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This report studies the economic and social costs and benefits of a passenger car tire design service life of 100,000 miles (160,900 kilometers), retreading, and four resource recovery methods for solid waste tires: (1) cryogenics with recovered rubber use, mixed with asphalt, in repairing roads; (2) incineration of whole tires; (3) pyrolysis; and (4) landfill. Symbolic models of tire costs and benefits are presented along with a computer program for their calculation. A shift in new tire design service life is recommended, along with increased retreading and with solid waste tire processing by cryogenics for use as tire asphalt rubber in repairing roads. Three methods of producing 100,000 mile tires are proposed; one, the TTW 100,000 mile tire, is discussed in some detail.

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Markets, Profits, and Resource Recovery

by

Robert R. Westerman

Department of Management
School of Business and Public Administration
California State University Sacramento
Sacramento, California 95819

Contract No. 68-03-2401

Project Officer

Haynes C. Goddard
Solid and Hazardous Waste Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Two hundred million solid waste passenger car tires are generated each year in the United States; no adequate large scale systems for processing these tires are in operation, although many have been proposed, and some implemented on a small scale. Tire solid waste decreasing systems including (1) product redesign for longer life and (2) retreading have also been proposed. This report investigates the costs and benefits of tire resource recovery methods, retreading, and a tire design change to a longer service life of 100,000 miles (160,900 kilometers) in an effort to determine the best system for the management of solid waste tires.

Francis Mayo
Director
Municipal Environmental
Research Laboratory

ABSTRACT

This report studies the economic and social costs and benefits of a passenger car tire design service life of 100,000 miles (160,900 kilometers), retreading, and four resource recovery methods for solid waste tires: (1) cryogenics with recovered rubber use, mixed with asphalt, in repairing roads; (2) incineration of whole tires; (3) pyrolysis; and (4) landfill. Symbolic models of tire costs and benefits are presented along with a computer program for their calculation. A shift in new tire design service life is recommended, along with increased retreading and with solid waste tire processing by cryogenics for use as tire asphalt rubber in repairing roads. Three methods of producing 100,000 mile tires are proposed; one, the TTW 100,000 mile tire, is discussed in some detail.

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SECTION 1

WASTE TIRES: THE PROBLEM AND STRATEGIES FOR SOLUTION

Tires play a significant part in the lives of virtually everyone. In manufacture they create jobs and useful products; in use they are always as close to us as the wheels beneath our automobiles, vital to occupation, family activities, and safety; in tire retreading, splitting, and rubber reclaiming, worn tire carcasses provide the raw material for secondary manufacture of recycled tires, door mats, and used rubber. The jobs and products of the tire industry comprise a significant segment of the national economic system. Over two hundred million new tires are sold each year in the United States; Americans spend about nine billion dollars per year to purchase tires. The quantitative significance of tires is personally evident when one reflects upon how many tires he or she sees each day, a number probably in the hundreds, and when one considers that a set of four replacement tires costs today, on the average, $170. Obviously, the strategic management of the tires production, distribution, and consumption system involves variables of national and personal economic significance.

Unfortunately, tires wear out, and - although some small amounts are retreaded, split, reclaimed, and perhaps sent to relatively small scale projects such as artificial reefs - seventy percent of the waste tires generated each year require waste collection, processing, and solid waste disposal. Waste tires can affect society through: solid waste handling costs, litter, and scenic blight, and through the rapid use (rather than conservative use) of our limited natural resources. These undesirable aspects of tires shadow the benefits of the jobs, products, and profits created by the industry.

The system of tire manufacturing, consumption, and wastes affects is diagrammed in Figure 1. The components of this system are interdependent: a change in management policy with respect to one component will change the status of one or more other components. A change in new tire design towards the use of higher operating pressures, for example, will increase the number of tires able to be retreaded each year. Any one component segment of the system might be managed with little regard for costs imposed upon the other segments.

The focus of this study is upon the solid waste tires segment of the tires system. We examine and measure a broad range of costs and benefits, however, including profits, costs to consumers, and jobs affects. The broad scope of the study, in lieu of myopic environmental management, is appropriate if the tires system is to be managed with equal respect allotted to each

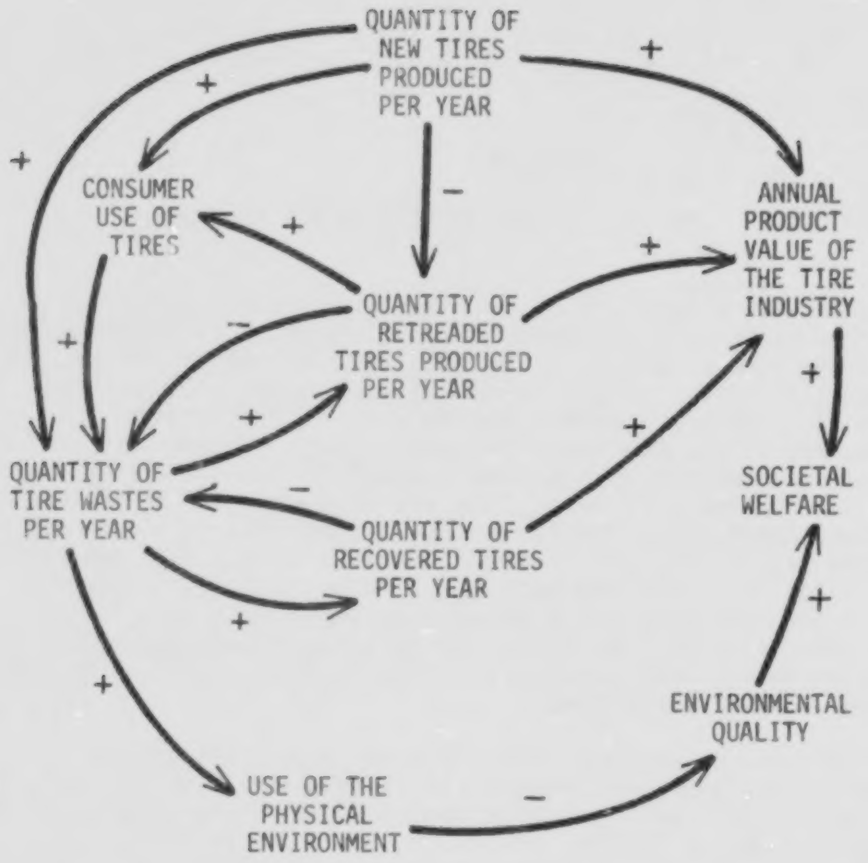
QUANTITY OF NEW TIRES PRODUCED PER YEAR
CONSUMER USE OF TIRES
ANNUAL PRODUCT VALUE OF THE TIRE INDUSTRY
QUANTITY OF RETREADED TIRES PRODUCED PER YEAR
QUANTITY OF TIRE WASTES PER YEAR
SOCIETAL WELFARE
QUANTITY OF RECOVERED TIRES PER YEAR
ENVIRONMENTAL QUALITY
USE OF THE PHYSICAL ENVIRONMENT
+
−

Figure 1. The Tires Industry System.

Note: Arrows indicate interaction between system components; plus and minus signs indicate increases and decreases in the attributes of the system components; minus signs imply that the relationship between the attributes is inverse. For example: as the quantity of new tires increases, the solid waste quantity increases; as the tire solid waste quantity increases, the use of the physical environment as a solid waste absorbing sink increases, and environmental quality decreases; as environmental quality decreases societal welfare decreases. On the other hand, as the quantity of new tires produced increases the product value of the tire industry increases and this can be said to increase societal welfare. Obviously, it is important to include a wide scope of costs and benefits in a study on tires management.

segment.

Over two hundred million solid waste tires are generated each year in the United States (See Figure 2). In this study we provide information and insight concerning the best set of alternatives for management of these tires. The alternatives discussed can be highly profitable for selected firms in the tire industry. They can provide the public with significant cost savings. They are, however, unconventional, and will require changes in management attitudes before acceptance.

This report is intended for several audiences: (1) for federal legislators and policymakers and their staffs; (2) for strategic decisionmakers in tire manufacturing, retreading, and solid waste tire processing; and (3) for students interested in an interdisciplinary case which synthesizes and quantitatively evaluates public and private economic, social, technical, and environmental costs and benefits of waste reduction (Source Reduction), recycling, and resource recovery alternatives. The technical feasibility, marketing, and economic analyses of the waste reduction alternative, the 100,000 mile tire, should be of special interest to all intended readers.*

PROFITS AND SOLID WASTE MANAGEMENT ALTERNATIVES

A specific focus of our work is Source Reduction; we examine the meaning and implementation of the solid waste decreasing Source Reduction alternative for tires. Both solid waste quantities and new product quantities are determined by manufacturers' product design service lives. We find that a 100,000 mile design tire service life can provide significantly improved total profits for a number of tire manufacturers and, at the same time, can reduce solid waste tires by sixty to seventy-five percent. 100,000 mile tires can decrease the costs of tire services for consumers, they can conserve resources, and can preserve (not use for disposal) the physical environment. This can be achieved with the same total product value for the tire industry as might normally be expected in coming years; 100,000 mile tires can create additional manufacturing jobs for a few years. Those manufacturers who capture the market can obtain fantastic profits. The problem with this alternative is, as with the current shift to steel belted radial tires, which manufacturers will realize these profits? This is an income distribution problem. Also of concern is how and when will those, displaced by change, adapt.

Another focus of the study is upon retreading. Retreading is recycling. Retreading provides the same profits, solid waste reduction, consumer cost, conservation, and environmental quality benefits as 100,000 mile tires. Increased retreading creates jobs. Yet retreading has been limited by manufacturing practices and by public perceptions of retreaded tires. We demonstrate, and measure, the prominent potential of retreading as a tire systems management alternative.

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*100,000 miles is equal to 160,935 Kilometers. Conventional 40,000 mile steel belted radial tires are 64,374 Kilometer tires. The 100,000 and 40,000 mile labels are used, in this report, as names rather than as numerical values. The Kilometric equivalents are repeated whenever the actual measurement of length is of importance.

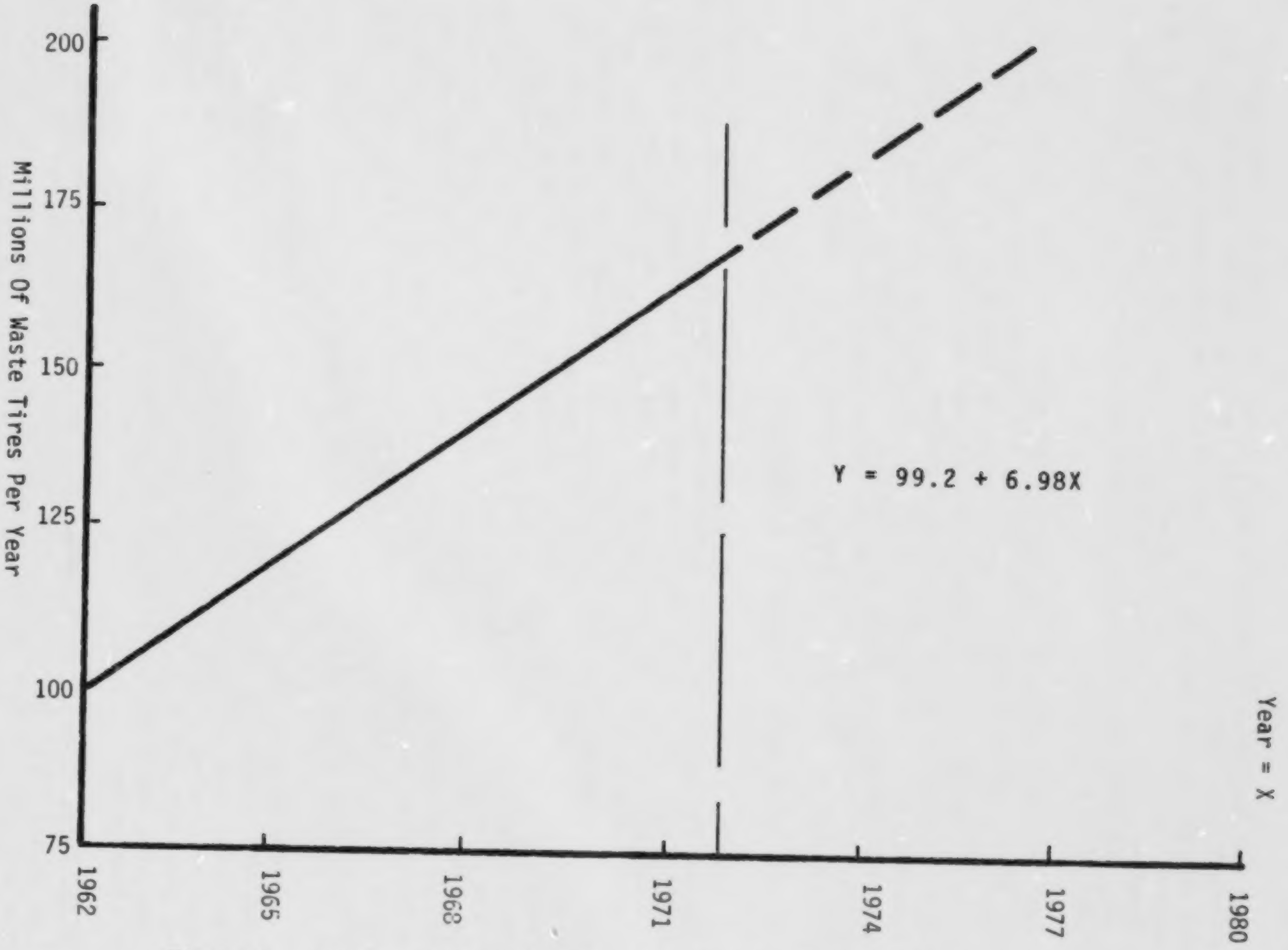

Figure 2. Annual solid waste car tires 1962 to 1972 and forecast.

The longer service life design and retreading alternatives lack the promotion and glamour of the tire resource recovery technologies. Many persons do not regard these as serious solid waste management alternatives. Increased service life and retreading are feasible, important, and viable waste management alternatives, however. It is technically feasible, today, to manufacture passenger car tires that will last, on the average, 100,000 miles (160,935 Kilometers). Retreading can be carried out in such a quality controlled fashion so as to make retreaded tires desirable to the public. Both of these waste decreasing alternatives can be considered akin to providing solid waste disposal capacity through avoiding the need for it. The waste reducing management strategies are alternatives to resource recovery.

This is not a generally accepted conclusion and, accordingly, we attempt to demonstrate this relationship in this study. If we decrease the quantity of solid waste tires generated each year by seventy-five percent then we will need seventy-five percent less investment and annual operating costs for Pyrolysis, incineration, or other engineering oriented tire resource recovery facilities. The investment costs avoided through the use of 100,000 mile tires will amount to hundreds of millions of dollars; the operating costs avoided through this Source Reduction alternative will, in steady state, amount to at least 150 million dollars annually. Solid waste decreasing alternatives can, in this time of increasing inflation and cost consciousness, be of some economic and political value.

The Source Reduction and recycling methods, on the other hand, do not represent, by themselves, complete solutions; each year some quantity of tire solid waste remains. Consequently, at least one waste tire resource recovery method is needed along with Source Reduction and retreading. Resource recovery alternatives for solid waste tires have been studied for a period of over five years. These include Pyrolysis, incineration with heat recovery, and mixing scrap rubber with asphalt for use in repairing roads. We examine the relative economics of these processes in this study.

A final focus of this report is upon the desirability of tire resource recovery, recycling, and Source Reduction alternatives when conservation, environmental quality, and general public values are taken into consideration. We examine the economic worth of conservation and environmental quality.

LARGE SCALE PROFIT AND SOLID WASTE MANAGEMENT STRATEGIES

We study four major recovery alternatives for handling the tire solid waste stream in addition to the two waste decreasing alternatives:

1. Road Repairs - In this process scrap tires are processed by Cryogenics, shredding, and classification to obtain vulcanized rubber particles which can be mixed with asphalt for use in repairing roads. A thin layer of asphalt rubber prevents reflection cracking and prevents the need for some road repairs.

2. Landfill - This process involves shredding tires and burying the shreds

in the earth. Tires produce an inert non-polluting fill material. The tire rubber landfilled can be mined at a later date.

3. Incineration with energy recovery- Incinerators specially designed to handle whole tires are now in operation. Tires have a heat value similar to coal and exhibit promise in heat recovery and use as energy.

4. Pyrolysis/Destructive Distillation- In this process tires are subjected to heat in the absence of oxygen; they break down into oils, chars, and gasses which can be marketable.

5. Retreading- Worn tire carcasses, in good condition, are buffed to be round and uniform, and a new tread rubber is applied and cured. This enables the use of the carcass for a second life time and avoids tire solid wastes.

6. 100,000 mile tires- Passenger car tires that will last, on the average under normal conditions, 100,000 miles can be manufactured by varying operating pressure, tire size and width, and the quality of the tread rubber used in tire manufacture.

There are, in addition to these, other tire waste management alternatives. The alternatives chosen were selected because they seemed to promise large scale solutions rather than showcase demonstrations on a small scale.

SMALL SCALE SHOWCASE TIRE SOLID WASTE SYSTEMS

The manufacture of artificial ocean reefs is one current showcase solution for waste tires. The idea is good, the technology is simple, and reefs provide significant benefits for fish and for fishermen. The demand for tire reefs , however, is not likely to require even five million worn tires per year, while two hundred million solid waste passenger car tires are generated each year. From the perspective of scale then, artificial reefs are not a solution to the tire waste problem.

Many smallscale alternatives for handling waste tires exist. It seems probable that several of these will be important, in small scale, in tire waste management. These alternatives include:

- Artificial reefs
- Tire splitting and manufacture of doormats, gaskets, etc.
- Grinding for use as a soil conditioner
- Re-use intact for swings, bumpers for docks, etc.
- Shredding and manufacture of resilient surfacing
- Protein manufacture
- Chemical modification

Still a solution is needed for handling the preponderant portion of the annual solid waste tires stream which will not be processed by the combined capacities of these relatively small scale alternatives.

PRIORITY OF TIRES STUDY

The focus of our study upon tires seems to be so highly specialized as to be of little interest or importance as compared to the many problems of business and society. Quite the opposite is true. The consequences of implementation of ideas presented here impact on every consumer, on the tire industry, and on the physical environment. These consequences, no matter what the alternatives chosen, will involve millions to billions of dollars to process solid waste tires. The conservation aspects of tires management are significant: Each tire, in manufacture, consumes about seven gallons of oil. Four replacement tires cost the consumer $170 to $320 every few years. Tires should be an area of priority concern for government planners. Tire service life and retreading should be areas of increased profit oriented study for manufacturers.

PREVIOUS STUDIES

There has been quite a bit of study on solid waste tires carried out in recent years throughout the world; an extensive bibliography on solid waste tires, tire resource recovery, retreading, tire production, tire profits, and tire markets is included with this report. This study and its predecessor, however, are unique in that they combine all of the above listed factors, in comparable terms, and define and provide quantitative measures of the costs and benefits of various alternatives; these measures include measurement of environmental quality, conservation, and effects on employment.

SECTION 2

TIRE SOLID WASTE COST BENEFIT ANALYSIS

Choice from among competing solid waste management strategies should, to the extent possible, be based upon quantitative analysis of the costs and benefits associated with the strategies. The alternative is satisficing, judgemental decision based upon incomplete information.

Some guidelines for Cost/Benefit Analysis are:

1. Establish a framework matrix of cost and benefit categories, and inductively search the matrix for potential costs and benefits with respect to each alternative studied.
2. Specify the system of reference and measure incremental costs and benefits with respect to this system.
3. Define value. From whose viewpoint are we looking at value? Which costs and benefits are to be included in which definition of value?
4. Measure the costs and benefits over a common time period so that the numbers are comparable as rates.

Cost/Benefits Analysis usually enumerates the costs and benefits of each alternative, establishes the periodic timing of the costs and benefits, and calculates the net present value of the periodic costs and benefits. Our Cost/Benefit Analysis is slightly different in that we measure cost and benefit rates over a common short time period. Our present value calculations are slightly different from the conventional. We examine, below, the implementation of our guidelines for Cost/Benefit Analysis in the management of the tires system.

SCOPE OF THE STUDY: BENEFIT AND COST DEFINITIONS

The cost and benefit categories that we studied for tires are given in Table 1. This Table identifies the broad scope of the study and provides a framework for the analysis. Brief definitions of the costs and benefits are given in the Table; more detailed definitions are given in the paragraphs that follow. Explicit symbolic definitions are given in Appendix A. We found values for forty-eight of the sixty benefit and cost rates indicated in Table one. All costs and benefits were measured as incremental effects per tire per four years.

TABLE 1. BENEFITS AND COSTS FRAMEWORK: TIRES SYSTEM.

Management alternative	Alt. #	Benefit categories (j)					Cost categories (k)				
		1	2	3	4	5	1	2	3	4	5
Resource recovery Road repairs	1	B_{11}	B_{12}	B_{13}	B_{14}	B_{15}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Landfill	2	B_{21}	B_{22}	B_{23}	B_{24}	B_{25}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}
Incin. energy	3	B_{31}	B_{32}	B_{33}	B_{34}	B_{35}	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}
Pyrolysis	4	B_{41}	B_{42}	B_{43}	B_{44}	B_{45}	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}
Recycling Retreading	5	B_{51}	B_{52}	B_{53}	B_{54}	B_{55}	C_{51}	C_{52}	C_{53}	C_{54}	C_{55}
Source reduction 100,000 Mile	6	B_{61}	B_{62}	B_{63}	B_{64}	B_{65}	C_{61}	C_{62}	C_{63}	C_{64}	C_{65}
		Benefit definitions					Cost definitions				
Note: a negative benefit will also be treated as a cost, and a negative cost will be treated as a benefit.		Product value and decreased waste	Consumer and public costs avoided	Corporate profits tax transfers	Physical environment aesthetics	Conservation of materials	Tire collection and shredding	Production, processing and solid waste	Administrative and marketing	Corporate profits taxes	Job gains and losses

Benefits Definitions

A narrative description of each benefit category definition, detailed, when appropriate, for each of the six alternatives studied is provided below.

Product Value Benefits

Road Repairs-the value of rubber recovered from a solid waste tire when sold in bags for use mixed as asphalt rubber; the value of recovered steel was added to this.

Landfill-the sales value for otherwise unusable land which has been recovered by landfilling with shredded tires.

Incineration/Energy-the sales revenues of the energy recovered per tire as expressed in British Thermal Units and related to conventional fuels.

Pyrolysis-the sales revenues per tire from the Carbon, oil, and steel recovered.

Retreading-the difference between the sales revenues on a retreaded tire and the sales revenues on a new tire for which the retread is a substitute, the salvage value of the worn carcass after its retreaded life was added to the revenue difference. The salvage value was valued as in Road Repairs above. An alternative definition was also studied, this modified definition eliminated the revenues of the new tire; only the revenues obtained from the retreaded tire, plus the salvage value, were treated as a benefit. The first definition is appropriate when viewing the entire tire industry as an integrated whole; the second is appropriate when the business merits of retreading are taken alone from an independent retreader's viewpoint.

100,000 Mile Tires-the discounted sales revenues from two 100,000 mile tires (one sold at present and the other at year ten) plus the discounted salvage values of the two tires (as in Road Repairs above); from this is subtracted the discounted sales revenues of the five current 40,000 mile worn carcasses replaced by the 100,000 mile tires and the discounted sales revenues from the rubber and steel salvaged from the five solid waste tires processed for Road Repair. The sum of these affects is multiplied by a fraction representing the ratio of the planning period of the study (4 Years in this study) to the number of years included in the comparison of the 100,000 and 40,000 mile tires (20 Years in this study). This converts the quantity to be a rate per four years. Finally, the result of the calculations is multiplied times a term which adds the average interest earnable or able to be lost by this tradeoff each four years.

Decreased Waste Benefits

The landfill and administrative costs avoided by resource recovery were included as benefits for these alternatives. The worn tire storage, grading, batch collection, haul, handling, chopping, landfill, and administrative costs avoided by recycling and by Source Reduction are benefits.

Consumer and Public Cost Avoided Benefits

The consumer costs avoided include cost savings obtainable by tire users with retreaded tires as opposed to new tires, and the cost savings obtainable with 100,000 mile tires as opposed to current steel belted radials. The latter, of course, is dependent upon the costs and prices of 100,000 mile tires.

The public costs avoided benefits are peculiar to the Road Repair alternative. Tire Asphalt Rubber road repairs enable public highway agencies to repair roads less frequently; Asphalt Rubber avoids some road repairs completely thus saving money. This money could be invested to earn interest. The timing of these benefits is such that they must be calculated over a relatively long period of time, as with the 100,000 mile tire benefits. Consequently these benefits have to be adjusted to be a rate per four years so as to be comparable to the resource recovery alternatives.

Corporate Tax Transfer Benefits

The corporate taxes paid by profitable recovery, recycling, and 100,000 mile tire operations are available to society for whatever beneficial use they may be put to.

Physical Environment Aesthetics Benefits

Resource recovery, retreading, and 100,000 mile tires avoid the use of the land as a disposal sink; they preserve and conserve the physical environment. These benefits can be conservatively valued at the cost value of properly disposing of tires by sanitary landfill.

Conservation Benefits

Retreaded and 100,000 mile tires get more use out of the carcass of the tire; they require fewer carcasses per unit of time, and this conserves material resources and energy. Tire incineration conserves on the use of energy from conventional sources.

Costs Definitions

A narrative description of each cost category definition, detailed, when appropriate, for each of the six alternatives studied, is provided below.

Tire Collection Costs

Worn tires must be stored, handled, graded, shredded, collected and hauled; each of these operations involves some costs. We aggregate these as, "Collection" costs.

Production, Processing, and Solid Waste Costs

These costs include investment and overhead cost allocations together with the operational costs of labor, energy, and materials for each process. For 100,000 mile tires incremental production costs with respect to the cost of production of a 40,000 mile steel belted radial tire are system costs. For retreading, the difference in production costs for a new and a retread tire are included as negative costs. The solid waste tires disposal costs for the portions of the solid waste stream that remain under the waste decreasing alternative are included in this cost category.

Administrative and Marketing Costs

The resource recovery and recycling strategies involve additional administrative and marketing cost; the products produced must be managed. 100,000 mile tires, on the contrary, decrease production and sales throughput and, consequently, decrease administrative and marketing costs. A negative cost for 100,000 mile tires, a benefit in reality, accrues in this category.

Corporate Profits Tax Costs

When the recovery, recycling, and 100,000 mile tire operations are run on a profitable basis, they are accountable for corporate profits taxes; these are costs to the operating or production firms.

Job Gains and Losses

Resource recovery creates jobs; retreading creates jobs at the expense of new tire production jobs. 100,000 mile tires eliminate jobs after an initial period of years of higher employment. We valued these at the value of the increases or decreases in labor or personnel oriented costs associated with each alternative. We did not include the benefit of increased employment for 100,000 mile tires in the short run.

REFERENCE SYSTEM: 40,000 MILE TIRES

The system of reference which we used in measuring incremental benefits and costs was an all steel belted radial, 40,000 mile tire, system. Steel belted radial tires are the largest selling replacement tire; recently, radial tires dominated original equipment tire sales for the first time. This dominance will further increase replacement radial tire sales in a few years since radial tires should not be mixed in use with bias type tires.

The system of reference defines the numeric values of the costs and benefits. In our analyses, for example, the cost of retreading is the cost of retreading a steel belted radial tire rather than a belted bias tire. For the 100,000 mile tire, costs and benefits are measured as increments, or decrements, as compared to the costs and benefits of producing and disposing of a current steel belted radial tire. The values assigned to these costs and benefits would be different if we used the belted bias tire as our reference. Steel belted radial tires are the proper system of reference for the present and coming years.

DIFFERENT VIEWPOINTS ON VALUE: VALUE DEFINITIONS

Value, the sum of the present value of the benefits of an alternative minus the present value of the costs, varies according to the decisionmaker carrying out the analysis. One measure of value is the standard business value (SBV) "revenues minus costs". A rate of value (reference Table 1), according to this definition, would be, for the tire manufacturers as an industry and for the "ith" recovery or reduction alternative:

$$SBV_i = B_{i1} - \sum_{k=1}^{4} C_{ik} \qquad i=1,\ldots,6$$

For the tire rubber asphalt alternative we studied a modified definition of value; this definition excluded cryogenics from the process, it included only tire collection and shredding:

$$SBV_{1m} = B_{1i} - C_{11}$$

Private tire manufacturers, dealers, and retreaders within the tire industry would see value from a different viewpoint than that of the industry. From the integrated industry viewpoint, increased retreading is at the expense of cheap new tire sales; C_{ik} would include the opportunity costs of the new tire sale foregone. This viewpoint truly represents some tire dealers. For those primarily in retreading, however, the objective is to sell as many retreads as possible. There is no opportunity cost of not selling a new tire for these retreaders. Similarly, a manufacturer selling 100,000 mile tires to the automobile companies would not be overly concerned that his increased profits were at the expense of an independent tire dealer. The increased profit of 100,000 mile tires goes to one group of persons within the industry; the opportunity costs of new tires not sold accrue to a separate group of persons. From the viewpoint of a single private manufacturer or retreader, then, our standard business value definition (reference Table 1) would be modified, for alternatives five (retreading) and six (100,000 mile tires), so as not to include the opportunity cost of a new tire not sold. (In the definitions below "m" stands for "modified".)

$$SBV_{im} = B_{i1m} - \sum_{k=1}^{4} C_{ik} \qquad i=5,6$$

A socially or public oriented measure of value (LEGV) might include, for recovery or reduction alternative "i", all of the benefits and costs of Table 1.

$$LEGV_i = \sum_{j=1}^{5} B_{ij} - \sum_{k=1}^{5} C_{ik} \qquad i=1,\ldots,6$$

This is the decision criterion which is applicable for federal legislators in their decision making on the desirability of product standards such as a requirement that new tires be designed for a service life of 100,000 miles (160,935 Kilometers). All of the cost and benefit factors of Table 1 may be of interest to this public decision.

On the other hand, most strategic management changes, not just environmentally oriented changes, have effects of increasing or decreasing employment levels. Business managers routinely make decisions affecting employment. Layoffs are certainly enacted whenever business finds them necessary. If this were not so, no one would ever be displaced from his or her job. All organizations and programs would grow monotonically. Employment effects are a significant emotional and political issue. We would argue that employment effects, which are already counted and valued in the product value section of our benefits (or costs depending upon the sign), should not be double counted or allowed to override all other considerations.

With this in mind we investigated a second social value definition which excludes the employment effects:

$$LEGV_{im} = \sum_{j=1}^{5} B_{ij} - \sum_{k-1}^{4} C_{ik} \qquad \begin{array}{l} i=1,\ldots.6 \\ m=\text{"modified} \end{array}$$

These several different measures of value are all important in making tire system decisions.

PLANNING HORIZON AND COST/BENEFIT RATES

The concept of a planning horizon which is common to all of the six alternatives studied, and the associated idea of measuring costs and benefits as rates per unit of time, are demonstrated in Table 2. In a twenty year period we might use five 40,000 mile steel belted radial tires or two 100,000 mile tires per axle. The benefits and costs of the five 40,000 mile and two 100,000 mile tires are fair in comparison. A twenty year planning horizon is appropriate to this situation.

As an example benefit calculation, let us look at the difference in profits between the alternatives shown. The five 40,000 mile tires will obtain, for tire dealers, \$212.95 profits each twenty years. The present value of these periodically timed cash flows, when discounted at a rate of twenty percent, is \$73.85. Alternatively, tire sellers may sell one 100,000 mile tire at time zero and another at the beginning of year eleven. The gross profits from the two 100,000 mile tires total \$140; the present value of this profit is \$79.45. Consequently, the tire industry can make \$5.60 more profit each twenty years with the 100,000 mile tire alternative. This is a benefit to the tire industry.

The \$5.60 profit per twenty years is a rate of gross profits as compared to five 40,000 mile tires. We converted it to a rate per one 40,000 mile

TABLE 2. TIRE SYSTEM BENEFITS AND COSTS OVER 20 YEARS

Yr	40,000 mile tire		100,000 mile tire	
	Benefits	Costs	Benefits	Costs
1	Dealers gross profit $42.59	Consumer purchases 1 new tire @ $65.50; 30 Lbs. materials used in manufacture	Dealers gross profits $70	Consumer purchases 1 new tire @ $100; 58 Lbs. materials used; incremental manufacturing costs of approx. $7.50
5	Dealers gross profit $42.59	Consumer purchases 1 new tire @ $65.50; 30 Lbs. materials & ¼ cu. ft. physical environment used; $1 solid waste cost	....	....
9	Dealers gross profit $42.59	Consumer purchases 1 new tire @ $65.50; 30 Lbs. materials & ¼ cu. ft. physical environment used; $1 solid waste cost	....	....
11	....	....	Dealers gross profits $70	Consumer purchases 1 new tire @ $100; 58 Lbs. materials used; incremental manf. costs of approx. $7.50; ¼ cu. ft. physical environment used & $1 solid waste tire processing cost
13	Dealers gross profit $42.59	Consumer purchases 1 new tire @ $65.50; 30 Lbs. materials & ¼ cu. ft. physical environment used;$1 solid waste cost	....	....
17	Dealers gross profit $43.59	Consumer purchases 1 new tire @ $65.50; 30 Lbs. materials & ¼ cu. ft. physical environment used;$1 solid waste cost	....	....
20*	....	¼ cu. ft. physical environment used; $1 solid waste processing cost	....	¼ cu. ft. physical environment used; $1 solid waste tire processing cost

*All years (YR) listed are timed at the beginning of the year except for year twenty which is meant to be the end of the year tire. This is equivalent to a rate per four years since one 40,000 mile tire lasts four years at the annual automobile use of 10,000 miles which is characteristic in the United States. Consequently, we show that a $1.12 benefit per four years accrues to tire sellers when 100,000 mile tires are sold at the profit rate shown. The benefits, in this case, represent average discounted profits allocable to a four year period.

The twenty year planning horizon, then, is used only to assist in obtaining cost and benefit rates; on occasion we use a ten year horizon for this purpose. The cost and benefit horizon for this study is four years. The five costs and benefits listed in Table 1 are calculated, for each of the six alternatives studied, on a four year basis with respect to a 40,000 mile solid waste tire. The implication is that the rates determined will maintain their relationships to each other for some undetermined period extending into the future.

DATA VALUES AND PARAMETRIC ANALYSES

The data values utilized in this study are estimates. Variation in data values could lead to changes in the conclusions reached. The value of 100,000 mile tires and of tire asphalt rubber, for example, vary with the interest/discount rate used in the analysis. We utilize our best data estimates in our basic analysis and, in recognition of the possible affect, on conclusions reached, of the data chosen, we investigate variations in prices, costs, the discount rate, and the interest rate. These parametric analyses, together with the alternative value definitions discussed above, allow the reader to understand better the structure of this tire system decision apart from the specific data utilized. Consequently the study will be of use even to those who might disagree with specific data values.

Explicit symbolic models representing the cost and benefit rates are detailed in Appendix A; the computer program, TIREC, used to calculate these value rates is listed as Appendix B. A study of the size and scope of this study defies detailed examination but by the most fastidious interested persons. With this in mind, this and the next chapter summarize and reference the more detailed work given in the several appendices.

SECTION 3

THE MANAGEMENT OF SOLID WASTE PASSENGER CAR TIRES: ANALYSIS AND CONCLUSIONS

The symbolic definitions of benefits and costs given in Appendix A and briefly described in Section 2 were programmed for calculation by computer into a program entitled, "TIREC", which is listed in Appendix B. The data values which were input to TIREC are listed in Appendix C. TIREC calculates the sixty cost and benefit value rates of Table 1. These are combined into the standard business and social values described in Section 2. We present and discuss, in this section, actual values, benefits, and costs as well as material developed in the Appendices. We analyze the tire management systems and draw conclusions relating to optimal systems management.

SUMMARY OF CONCLUSIONS

The TIREC cost/benefit analysis provides explicit information supporting three conclusions:

1. Tire solid waste decreasing alternatives are economically preferable to engineering resource recovery alternatives; both retreads and 100,000 mile new tires can be privately manufactured at a profit while providing substantial conservation, consumer cost, and environmental benefits.

2. The repair of roads using tire asphalt rubber is the economically preferable large scale end use (disposal method) for the rubber in worn tires; tire asphalt rubber provides benefits to society through road repair costs which can be avoided as a result of the process.

3. Tire resource recovery by pyrolysis, incineration with energy recovery, and landfill cannot be operated, at this time, at a profit. These solid waste tire handling methods will not be implemented by industry without governmental prodding. There are environmental and conservation benefits which provide social justification for these processes, however.

These conclusions are significant in that they indicate that the economical solution to the solid waste tires problem lies in alternatives not currently promoted by either the tire industry or by the federal government. The conclusion that waste prevention is economically superior to resource recovery is especially significant since this is a systematically determined conclusion based upon facts and data documented in this report. This waste reduction conclusion has ramifications for several federal solid waste management programs as well as for tires.

Two other conclusions were reached in developing the information needed.

4. It is technically feasible, at this time, to produce tires which will last, on the average, 100,000 miles (160,935 kilometers). These tires can be safer and less costly, on a cost per mile basis, than current steel belted radial tires. They can be manufactured for less than $30 and sold for about $100 each. 100,000 mile tires have substantial benefits upon which to build a marketing campaign. They promise significant total industry profits as compared to current steel belted radial tire total industry profits. Three preliminary 100,000 mile tire designs are identified later in this section and are discussed in Appendix E.

5. Retreading is an existing solid waste recycling business which is operating on its own merit at a profit. It is possible to dramatically increase the number of tires retreaded, however. New tires could be designed to enhance retreadability; the tire within a tire design could be used to provide increased safety. In this design a second tire is built inside each tire so that when the outside tire fails the inside tire still operates safely. Retreading methods, equipment, and materials could be improved to provide a better product. Retread markets could be expanded with better communication to consumers concerning the recommended uses and limitations of retreads.

VALUES, COSTS, AND BENEFITS

The basic sixty benefits and costs calculated by TIREC are given in Table 4. The values calculated based upon these and upon modification of two of these are presented in Table 3 below. Table 3 identifies the relative values of source reduction, recycling by retreading, tire asphalt rubber, and other resource recovery alternatives.

TABLE 3. BUSINESS AND SOCIAL VALUES PER WASTE TIRE

Strategy	Standard business values		Social legislative values	
	SBV_i	SBV_{im}	$LEGV_i$	$LEGV_{im}$
Resource recovery				
Road repairs	-$ 1.19	$ .01	$31.27	$31.75
Landfill	-$ 1.09	-$ 1.09	$ .11	$ .08
Incineration energy	-$ 1.20	-$ 1.20	$ .66	$ .50
Pyrolysis	-$ .66	-$ .66	$ 1.77	$ 1.49
Recycling				
Retreading	-$24.85	$ 6.17	$27.81	$30.49
Source Reduction				
100,000 miles	$ 2.43	$ 6.27	$19.38	$29.07

Note: The SBV_i and SBV_{im} columns are estimates of the revenues and costs per solid waste tire per four years; these are the sums of benefit number one and the first four costs of Table 4 except as noted in definitions on pages 13 and 14. The LEGV values include all of the benefits of Table 4 except that $LEGV_{im}$ excludes employment effects (C_{i5}).

TABLE 4. BENEFITS AND COSTS PER STANDARD TIRE OR PER FOUR YEARS

Management alternative	Alt. #	Benefit categories 1	2	3	4	5	Cost categories 1	2	3	4	5
Resource recovery											
Road repairs	1	1.15	38.69	0.00	1.19	5.00	1.14	11.42	1.71	0.00	0.48
Landfill	2	0.10	0.00	0.00	1.19	0.00	1.14	0.05	0.01	0.00	- 0.03
Incin. energy	3	0.53	0.00	0.00	1.19	0.53	1.14	0.52	0.08	0.00	- 0.16
Pyrolysis	4	0.96	0.00	0.00	1.19	0.96	1.32	0.25	0.06	0.00	- 0.29
Recycling											
Retreading	5	-34.15	47.28	1.61	0.60	5.86	1.08	-11.98	0.00	1.61	2.68
Waste reduction											
100,000 miles	6	0.79	22.70	1.19	0.55	2.20	0.45	- 2.43	- .85	1.19	9.69
		Benefit definitions					Cost definitions				
Note: a negative benefit is, in reality, a cost. A negative cost is a benefit.		Product values and decreased wastes	Consumer costs avoided [c]	Corporate profits tax transfers	Physical environment aesthetics	Conservation of materials	Tire Collection and Shredding	Production, processing, and waste	Administrative and marketing	Corporate profits taxes	Job gains and losses

100,000 mile tires, at a price of $107 each - a production cost of about $30 each - and a discount rate of twenty percent, display a high relative value from all viewpoints: Each 100,000 mile tire increases the national tire industry product (value of the tire industry) by $2.43 per four years; for a single private tire manufacturer each 100,000 mile tire promises $6.27 in net profits per four years; 100,000 mile tires have eleven times the value of the most optimistic representation of the socio-economics ($LEGV_6$) of pyrolysis (destructive distillation), a resource recovery method highly recommended and promoted by the tire industry; the value of 100,000 mile tires is 176 times as great as that of landfill, the current tire solid waste disposal method, when social values concerning quality of the physical environment, conservation of materials, and cost per year of tire services for consumers are taken into account.

These value relationships include a $9.69 social cost (per 100,000 mile tire each four years) associated with decreased employment in the tire industry. This social unemployment cost was measured as the value of the labor not needed each four years as a result of the decreased production throughput associated with 100,000 (versus 40,000) mile tires. When this employment cost is excluded from the value definition, 100,000 mile tires are about twenty times as valuable as pyrolysis.

100,000 mile tires are a most valuable alternative. When it is considered that each 100,000 mile tire could be retreaded for a second life and then treated for resource recovery use in road repairs. A change in tire product design such that automobile passenger car tires obtain, on the average - under normal conditions of use - 100,000 miles is desirable from both the private profit oriented and the public socially oriented viewpoints.

The technical feasibility, marketability, and the effect of parametric variations in the $107 price, $30 production cost, and twenty percent interest rate are discussed later in this section. Generally, these do not alter the conclusion favoring 100,000 mile tires.

The second factor evident from the basic research results of Table 2 is that retreading is a highly profitable and socially valuable business. A retreaded tire promises $6.17 in profit to an independent retreader. When the materials conservation, decreased solid wastes, and consumer cost social benefits are included in the analysis, retreading a-sumes a value in excess of the 100,000 mile tire value. From the viewpoint of the tire industry as a whole, however - or from the viewpoint of a tire dealer selling both retreads and new steel belted radial tires - retreads are costly. A new steel belted radial tire promises $24.85 more profit than a retreaded tire. It is not to the tire dealers benefit to sell more retreads if these sales are at the expense of new steel belted radial tire sales.

Both the 100,000 mile tire design and retreading should be implemented prior to resource recovery, according to their high values.

Cryogenics, with the use of recovered rubber in road repairs, is the best, most valuable, tire resource recovery method. The tire asphalt rubber process loses $1.19 per tire processed with cryogenics (SBV_1). When cryogenics is not used, the production of recovered tire rubber just about breaks even (SBV_{im} = .01). These representations do not include the cost of repairing roads. As a public program, when the social benefits of road repair costs avoided are taken into consideration (a value of $38.69, Table 3) tire asphalt rubber moves from the loss or break even situation to a position of relatively overwhelming value as a solid waste tire handling method. Each 40,000 mile tire processed by cryogenics and used in tire asphalt rubber to repair roads provides a $30.49 net value to all concerned.

Landfill, tire incineration with energy recovery and pyrolysis (destructive distillation) are costly business propositions. For the 200,000,000 solid waste tires generated in the United States each year these would cost the tire industry 132 million dollars to 218 million dollars per year; the tire industry ends up with most old tires when traded in and, accordingly, the responsibility for disposal. Obviously these alternatives will not be implemented, in large scale, by the tire industry, without governmental prodding.

Increased incineration or pyrolysis of solid waste tires is not without benefits, however. Tire resource recovery creates jobs, avoids use of the environment as merely a waste disposal sink, and conserves resources in addition to providing the values of the recovered products. Landfill, as a land reclamation process, demonstrates some of these benefits. The values of these second place resource recovery processes, when all benefits and costs are included, are positive: Each solid waste tire provides net benefits of:

Landfill	$ .11
Incineration/energy	$ .66
Pyrolysis	$1.77

We examine to costs and benefits aggregated to produce the values of Table 2 in four technical subsections: 100,000 Mile Tires, Retreading, Tire Asphalt Rubber, and Other Resource Recovery Technologies.

100,000 MILE TIRES

Technical Feasibility

It is technically feasible, at this time, to produce tires that will last, on the average, 100,000 miles (160,935 kilometers). Truck tires, in current practice, obtain 115,000 miles (185,035 kilometers) of original life before the first retreading. Three technological alternatives for the development of 100,000 mile passenger car tires are:

1. Large High Pressure Tire (LHP). Redesign autos to use the larger tire sizes; increase operating pressure in the tire and redesign the automobile suspension system to absorb some of the increased harshness of the ride.

2. Thick Tread-Wide Tire (TTW). Use truck tread rubber, increase the thickness of the tread rubber on conventional passenger steel belted radial tire carcasses to the maximum safe thickness; widen the tire as in current sporty wide tires.

3. Durable Tread Rubber (DTR). Develop a highly durable tread rubber which, with the same tread thickness as in current passenger tires, and at the same low inflation pressures, will obtain 100,000 miles.

The LHP and TTW 100,000 mile tires are currently feasible designs. The DTR 100,000 mile tire is, apparently, yet to be developed. These designs are discussed in Appendix E.

Production Costs

We calculated a production cost for 100,000 mile TTW tires; these are essentially current steel belted radial tires with increased width and tread depth. The production cost, H, may be represented as:

H = the cost of a current steel belted radial tire PLUS
the additional materials cost PLUS
the additional labor costs PLUS
an additional allocation for overhead expenses

$$H = C_r(1 + S_m H_m + S_L H_L + S_o H_o)$$

Where:

C_r = the cost of producing a current steel belted radial passenger car tire, excluding manufacturer's profits

S_m = the decimal fraction of a steel belted radial tire's production costs attributable to materials only

H_m = a number representing the additional amount of materials needed to obtain 100,000 miles

S_L = the decimal fraction of a steel belted radial tire's production cost attributable to labor, only

H_L = a number representing the additional labor needed to produce a 100,000 mile tire

S_o = the decimal fraction of a steel belted radial tire's production costs attributable to overhead

H_o = a number representing the additional overhead which must be allocated to a 100,000 mile tire.

Our estimated production cost is:

$$H = 21.68(1 + (.475)(.45) + (.275)(.25) + (.250)(.40)$$

$$= \$29.92$$

The TIREC program calculated this cost to be $29.71. 100,000 mile tires, then, excluding manufacturer's profits, cost about $30 each to produce.

Sales Price

Tire manufacturers would sell 100,000 mile tires directly to the automobile manufacturers for use as original equipment. Tire sellers have the option of selling 40,000 mile tires that last four years (at 10,000 miles per year) or TTW 100,000 mile tires that last ten years. We formulated the alternative sales of two 100,000 mile tires or five 40,000 mile tires as a present value problem to determine the discounted gross profits needed to make the two alternatives equally attractive to the tire industry.

TABLE 5. GROSS PROFITS OF FIVE 40,000 MILE TIRES

Beginning of year	PV factor 20%	Steel radial gross profits	Present value of gross profits
1.0	1.000	\$ 42.59	\$ 42.59
5.0	.482	\$ 42.59	\$ 20.53
9.0	.233	\$ 42.59	\$ 9.92
13.0	.112	\$ 42.59	\$ 4.77
17.0	.054	\$ 42.59	\$ 2.30
	Total	\$212.95	\$ 80.11

\$80.11 gross profits is earned on five 40,000 mile tires over a twenty year period. In place of these we propose two 100,000 mile tires, one sold at present and the other at the beginning of year eleven. We set the gross profit of the current sale of a 100,000 mile tire (G_L) plus the present value of the gross profits on the 100,000 mile tire sale at year eleven ($.162G_h$) equal to the profits on the alternative five 40,000 mile tire sales:

G_h : 20% discount rate

$$G_h + .162G_h = 80.11$$

$$G_h = \frac{80.11}{1.162} = \$68.94$$

\$68.94 profit is needed on a 100,000 mile tire in order to provide the same gross profits for the tire industry as is earned currently with 40,000 mile tires. We added this estimate of gross profits to the \$30 production cost of a 100,000 mile tire to determine a reasonable price for a 100,000 mile tire. The price of a 100,000 mile tire, according to this procedure, should be \$98.94 or about \$100.

Marketability

Consumers will buy 100,000 mile tires at prices above \$100. In a preliminary market survey virtually all of the respondents indicated that they: (1) were interested in such tires, and (2) were willing to pay from \$30 to \$150 additional for each tire (See Appendix E). There are several reasons for this interest:

1. Consumers can obtain 100,000 mile tires when they buy a new car and can, conveniently and accordingly, include ten years of tire costs in the financing of the vehicle.

2. Consumers can obtain 100,000 mile tires at a price which, in present value analysis, is cheaper than the costs of the alternative four sets of tires. Consequently consumers can obtain a lower cost per mile.

3. Purchase of 100,000 mile tires will eliminate the need for at least three distasteful trips to purchase replacement tires; this will include fuel savings, time savings, and avoidance of the confusion associated with hundreds of tire brands and types.

4. Consumers can recoup their investment if they sell their car after, for example, three years; the factor of having good tires with 70,000 miles of treadwear left will be an asset which will increase the resale price and sales potential of the three year old car.

5. Consumers can avoid public costs associated with waste tire disposal. Waste tire disposal involves, at the least, transportation costs, expensive shredders costs, and landfill costs. 100,000 mile tires eliminate sixty percent of the waste tires generated in any year and, accordingly, avoid sixty percent of the public tire waste handling costs which would otherwise be incurred.

6. Consumers are very much conscious of the needs for conservation and protection of environmental quality. They will buy 100,000 mile tires because they believe in the need for conservation and because they value quality of the physical environment.

7. 100,000 mile tires will provide added safety to the consumers vehicle and to vehicles with which consumers interact on the road. Safety studies have indicated that baldness of tires is a significant factor contributing to accidents. 100,000 mile tires, with respect to this most important safety factor, would be much safer than current tires. 100,000 mile tires would not be likely to become bald until, on the average, 100,000 miles of service, 10 years of service life, were completed. Consequently 100,000 mile tires would eliminate much of the danger associated with bald tires. They would have a substantial amount of tread remaining during the last five to seven years of automobile use whereas current tires would either be balding or, perhaps replaced with cheap tires. Even if 100,000 mile tires were not inherently safe they could be redesigned to be safe via the tire within a tire design.

Disadvantages

There are several potential disadvantages to 100,000 mile tires. These include:

1. The selling prices are higher; demand for tires or cars may decrease as a result.
2. The losses per tire due to tires damaged and rendered unusable during service life will be higher.

3. 100,000 mile TTW and LHP tires will be heavier with a cost to consumers in terms of lower gasoline mileage.
4. 100,000 mile tires may alter the appearance of the vehicle.
5. 100,000 mile tires may have a more harsh ride than do current tires.
6. 100,000 mile tires may not handle as well as do current tires; traction characteristics may be different.
7. 100,000 mile tires will decrease employment in the long run.

We offer the following brief responses to these disadvantages:

1. The ability to finance the tires when the automobile is purchased should offset the effect of the high selling price.

2. The total losses due to damages during service life may be lower due to increased durability of 100,000 mile tires even though per tire losses are higher.

3. A rough calculation of the effect of the increased weight on gasoline mileage provides an increased cost of only $3.84 per 100,000 mile tire per four years (See Appendix E). This cost is not significant in comparison to the benefits of 100,000 mile tires.

4. The appearance of the vehicle need not be changed considerably to allow for 100,000 mile tires, even though it may be.

5. Consumers are willing to endure a more "harsh" ride than is obtained with current tires.

6. 100,000 mile tires may handle just as well as current tires; truck tires seem to do a reasonable job.

We do not argue with the disadvantage that 100,000 mile tires will decrease employment in the long run. The conclusion that 100,000 mile tires are desirable is, at the least, highly controversial. The longer service life idea is avoided by tire manufacturers and sellers. The decreased market volume, decreased employment, and the effects these have on the national economy are taken, by some, to be overriding considerations which preclude, or should preclude, consideration of 100,000 mile tires by industry and by public decisionmakers.

We included these market, employment, and macro-economic effects in our analysis: (1) An explicit measure of employment shifts or losses, represented as system costs, was calculated; (2) the price at which a 100,000 mile tire is to be sold was represented as a price which would provide profits equal to the discounted present value of the 40,000 mile tires which the 100,000 mile tire replaces. Consequently, little or no macro-economic change effects, and multiplication of macro-economic effects, in terms of Gross National Product (the Multiplier) are expected. GNP and the tire industry value remain relatively constant at the prices and costs of our basic analysis. Those who would cast doubt upon the efficacy of the 100,000 mile (160,935 kilometer) service life based upon these employment and macro-economic arguments might direct their analysis and comments toward how these effects were represented in this analysis rather than whether they were included.

Business Costs and Benefits

Table 6 studies two business oriented measures of profits for 100,000 mile tires based upon the TIREC costs and benefits of Table 4.

TABLE 6. MANUFACTURERS PROFITS: 100,000 MILE TIRES

SBV_6	SBV_{6m}	
		Benefits
\$ .79	\$25.57	B_{61} Product value and decreased wastes
\$ .79	\$25.57	TOTALS
		Costs*
\$ .45	\$ .45	C_{61} Tire collection and shredding
-\$2.43	\$11.90	C_{62} Production and solid waste
-\$ .85	\$ 4.17	C_{63} Administrative and marketing
\$1.19	\$ 2.79	C_{64} Corporate profits taxes
-\$1.64	\$19.31	Totals
\$2.43	\$ 6.26	Benefits minus costs

* A negative cost indicates, in reality, a benefit. The values shown were calculated in accordance with the formulas given in Appendix A at a business interest rate of twenty percent, a production cost of \$29.71, and a 100,000 mile tire sales price of \$107.

The first measure, SBV_6, includes incremental effects of 100,000 mile tires as compared to 40,000 mile tires and may be interpreted as saying that the gross product of the tire industry increases by \$2.43 per 100,000 mile tire each four years. The significance of this information is that 100,000 mile tires can be a viable business alternative as compared to current tires.

Even with the smaller production/sales volume taken into consideration each 100,000 mile tire provides \$.79 more revenues to a manufacturer/seller per four years (B_{61} = \$.79; Reference Table 6) than does the comparable displaced 40,000 mile tire. This increase represents both sales revenues and tire solid wastes costs avoided. Unlike resource recovery, however, 100,000 mile tires leave some solid waste tires requiring disposal each year; the remaining tire solid wastes, per 100,000 mile tire, cost \$.45. It is cheaper by \$2.43 (on a production cost per year of service life basis), over a four year period, to manufacture 100,000 mile tires than it is to manufacture 40,000 mile tires, even when the cost of landfilling the tire solid wastes remaining are included in the tradeoff (C_{62} = -\$2.43). Administrative and marketing costs with 100,000 mile tires are, at a minimum, $.85 cheaper per tire than the comparable costs of the 40,000 mile tires replaced. In fact, administrative and marketing costs are probably very substantially lower than this representation for 100,000 mile tires since tire manufacturers would be the 100,000 mile tire sellers and sales would be made directly to the automobile companies; retail administrative and marketing costs would be, in great part, eliminated. Finally, corporate profits taxes on a 100,000 mile tire will increase by $1.19 per four years as compared to taxes on a 40,000 mile tire. When all of these effects are combined the net evaluation of the 100,000 mile tire is very favorable; $2.43 more per 100,000 mile tire than for a 40,000 mile tire is realized (SBV_6 = $2.43). At a price of $107 each for 100,000 mile tires, a production cost of $29.71, and an expected rate of return on investments of twenty percent, 100,000 mile tires, as a business venture, compare very favorably with current 40,000 mile tires.

The employment effects, the C_{65} cost category, are not included in the business analysis value definitions (SBV's) since these are not costs to tire companies, but rather are social costs. Employment effects are discussed later in this section in the analysis of social values.

The second definition of Table 6, SBV_{6m}, (page 13) includes the total discounted benefits and costs per four years; these effects were not measured, as were SBV_6 effects, as incremental costs and benefits compared to 40,000 mile tires. The SBV_{6m} measure depicts the situation that 100,000 mile tire manufacturers/sellers would make net profits of $6.26 (including the costs of adequate tire solid waste disposal) per 100,000 mile tire per four years. A 40,000 mile tire, incomparison, makes only $2.56 in profits (See Table E-5) and even this figure should be decreased by tire solid waste costs to be comparable to the $6.26. This rate of profits, at a production cost of $29.71 and a sales price of $107, is high. Those who manufacture and sell 100,000 mile tires can make substantial net profits.

The $6.26 is a net profit rate; in actuality $25.06 in net profits would be realized at the time of sale. The customer, however, would not return for a repeat sales for ten years.

Social Costs and Benefits

Social values of the 100,000 mile tire alternative are given in Table 7. These include, for $LEGV_6$, four additional public benefits and the controversial additional cost of displaced jobs associated with the 100,000 mile tire alternative.

The additional benefits of 100,000 mile tires total $26.64, a very substantial amount in addition to the $.79 incremental product value benefit to the manufacturer. Consumers can save $22.70 each four years by purchasing 100,000 mile tires at $107 each as compared to current steel belted radial tires at $65.50 each. The increased corporate profits taxes, $1.19 per 100,000 mile tire, paid by the tire manufacturer/seller are paid to the public treasury and, hence, are available for any public benefit. Each 100,000 mile tire prevents the use of $.55 worth of the physical environment and conserves $2.20 worth of tire production materials each four years. These are benefits which should be taken into account in determining the desirability of 100,000 mile tires. Notably, they do not impinge directly upon the tire industry as costs or revenues of a conventional accounting sense.

TABLE 7. SOCIAL VALUES (LEGV): 100,000 MILE TIRES

$LEGV_6$	$LEGV_{6m}$	Benefits
$ .79	$ .79	B_{61} Product value and decreased wastes
$22.70	$22.70	B_{62} Consumer costs avoided
$ 1.19	$ 1.19	B_{63} Corporate profits tax transfers
$ .55	$ .55	B_{64} Physical environment preservation
$ 2.20	$ 2.20	B_{65} Conservation of materials
$27.43	$27.43	Total
		Costs
$ .45	$ .45	C_{61} Tire collection and shredding
-$ 2.43	-$ 2.43	C_{62} Production and solid waste
-$ .85	-$ .85	C_{63} Administration and marketing
$ 1.19	$ 1.19	C_{64} Corporate profits taxes
$ 9.69	$ -	C_{65} Job gains and losses
$ 8.10	-$ 1.64	Total
$19.33	$29.07	Benefits minus costs

The cost of displaced jobs associated with 100,000 mile tires is very substantial; each 100,000 mile tire eliminates, in the long run, $9.69 worth of labor employment. This "translates" to about 187,500 persons' employment being affected during a fifteen year period, 12,500 persons per year. (See page 134.)

Increased employment is a common economic objective of federal policies and, accordingly, an alternative which decreases employment may be considered costly. This type of thinking, however, supports: (1) the status quo, and (2) the concept that only those alternatives which increase employment are of value. Cannot an alternative which promotes efficiency for tire manufacturers and/or consumers, and efficiency in the use of materials and of the physical environment be of value? Are all organizations now in existence to grow larger and larger simply to increase employment? Should not new medicines be introduced, simply to maintain the rate of patient referral to medical doctors, to maintain the level of employment of doctors? The response is obvious. There are changes which decrease employment which are desirable to society.

The costs and benefits associated with 100,000 mile tires indicate that this is one such change. The social value ($LEGV_{6m}$) of 100,000 mile tires, excluding the employment effect, is $26.59, a very substantial amount. The social value including the employment effect is $16.89, still a very substantial amount. And 100,000 mile tires promise increased employment initially, an effect not included in our models. The decrease in employment occurs over a period of ten years or so; this period allows ample time for reaction to displacement from jobs in an orderly fashion. These considerations are discussed in more detail in Appendix E.

It may be noted that the value of 100,000 mile tires is dependent upon several data parameters included in our analysis; the values and conclusions discussed above may vary with changes in: (a) production costs; (b) sales prices; and (c) the discount rate. Figures 3 through 6, respectively, consider variation in these factors and the effects of these variations upon value.

Figure 3 indicates that, given a 100,000 mile tire price of $107 and a discount rate of twenty percent, any 100,000 mile tire production cost above $36 will decrease the profit oriented SBV_6 (Line AB) to below zero. At a production cost of $56 per 100,000 mile tire, the Business Value (SBV_6) drops to -$10; a $26 increase in production costs, in addition to the $30 cost we used to represent 100,000 mile tires, decreases the net business benefits by about $13 per tire. The business value of 100,000 mile tires is moderately sensitive to 100,000 mile production costs; a 55 percent decrease in net business benefits accrues to a 100 percent increase in production costs. The moderate stability of value with this parametric change is due to: (1) the ability of 100,000 mile tires to spread the increase in costs over ten years; and (2) the fact that no other business cost changes dramatically with changes in 100,000 mile production costs.

The social value ($LEGV_6$ and Line CB in Figure 3) is very sensitive to 100,000 mile tire production costs. A 100 percent increase in production costs precipitates a 176 percent decrease in the social value $LEGV_6$. This sensitivity is due to the combined production cost and employment effects. The social value modified to exclude decreased employment costs (Line DE representing $LEGV_{6m}$) is moderately sensitive to production costs, but never drops below $13 - even at production costs of $60.

The significance of Figure 3 in our analysis is that, ceteris paribus, our conclusion that 100,000 mile tires can be profitable to the tire industry holds good for a twenty percent increase over the $29.71 production cost representation of our analysis. The social value of 100,000 mile tires holds positive for a sixty-one percent increase in representation of 100,000 mile tire production costs. The argument that our analysis and conclusion is negated by an error in estimation of 100,000 mile tire production costs is questionable. Figure 4 demonstrates the relative importance of the various benefits and costs. Figure 4 shows the variation in costs and benefits associated with models of Appendix A. The costs and benefits not plotted did not vary with changes in production costs of 100,000 mile tires.

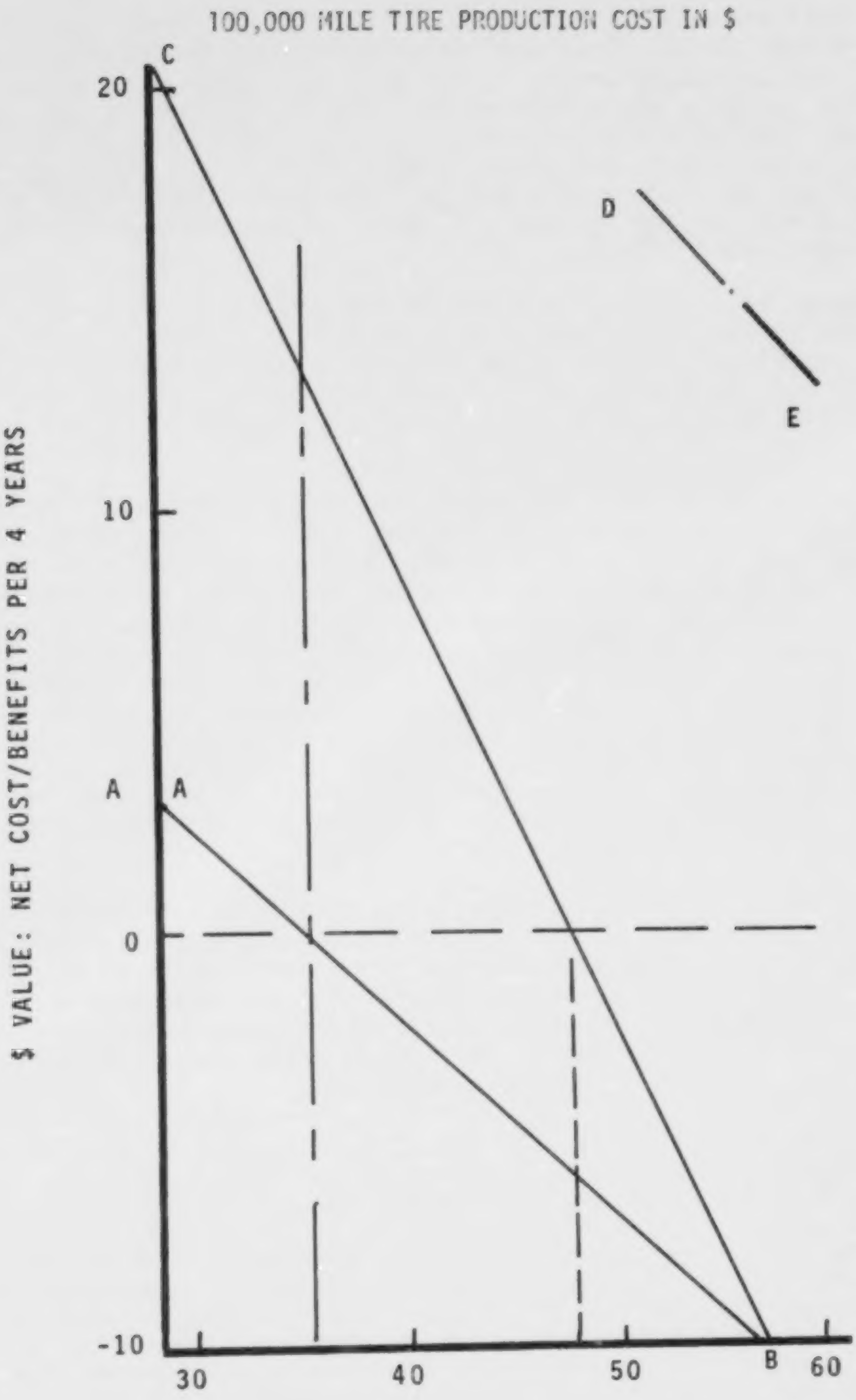

Figure 3. Production cost versus values 100,000 mile tires.

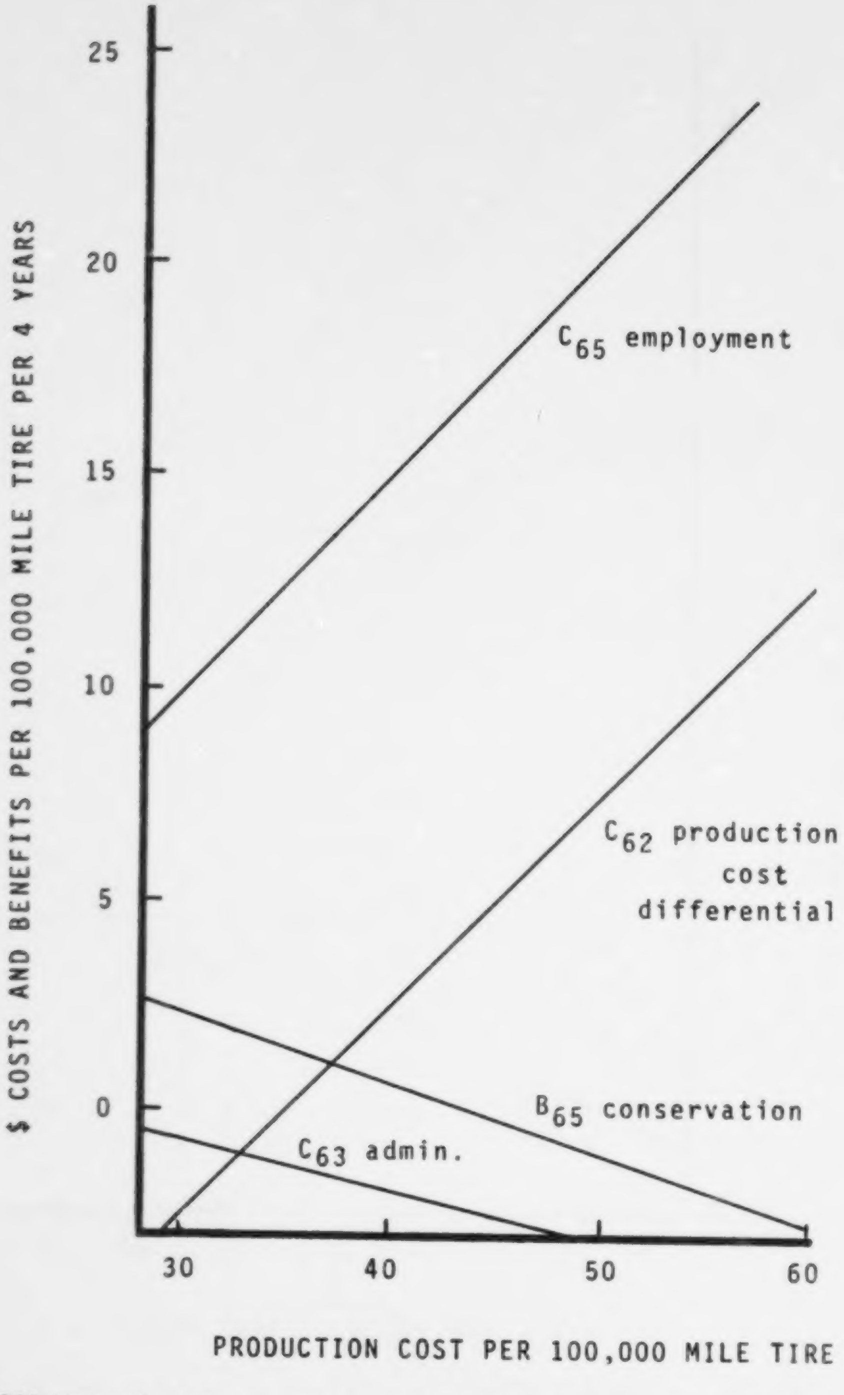

Figure 4. 100,000 mile tires: costs and benefits versus production cost.

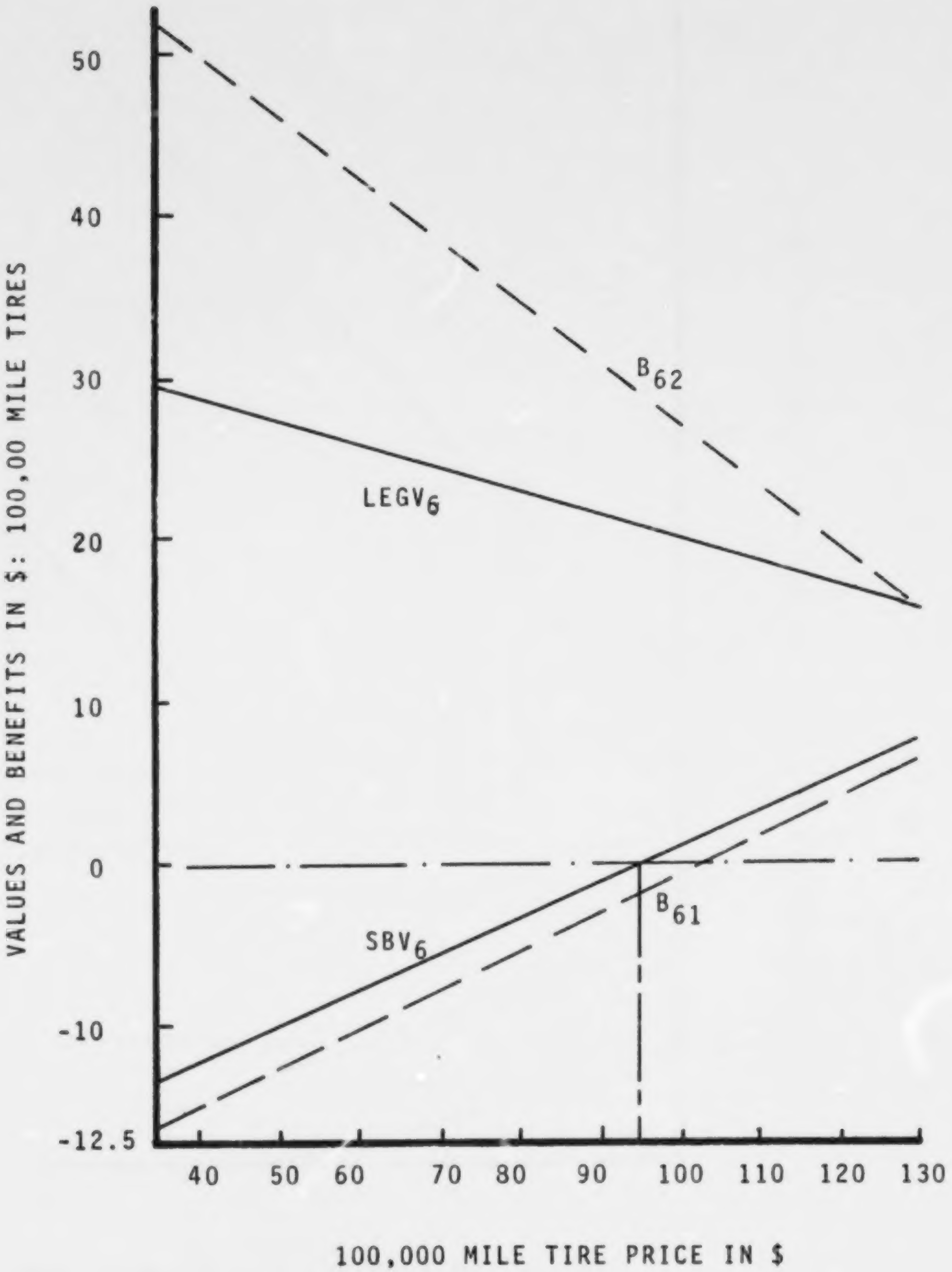

Figure 5. 100,000 mile tire price versus values and benefits.

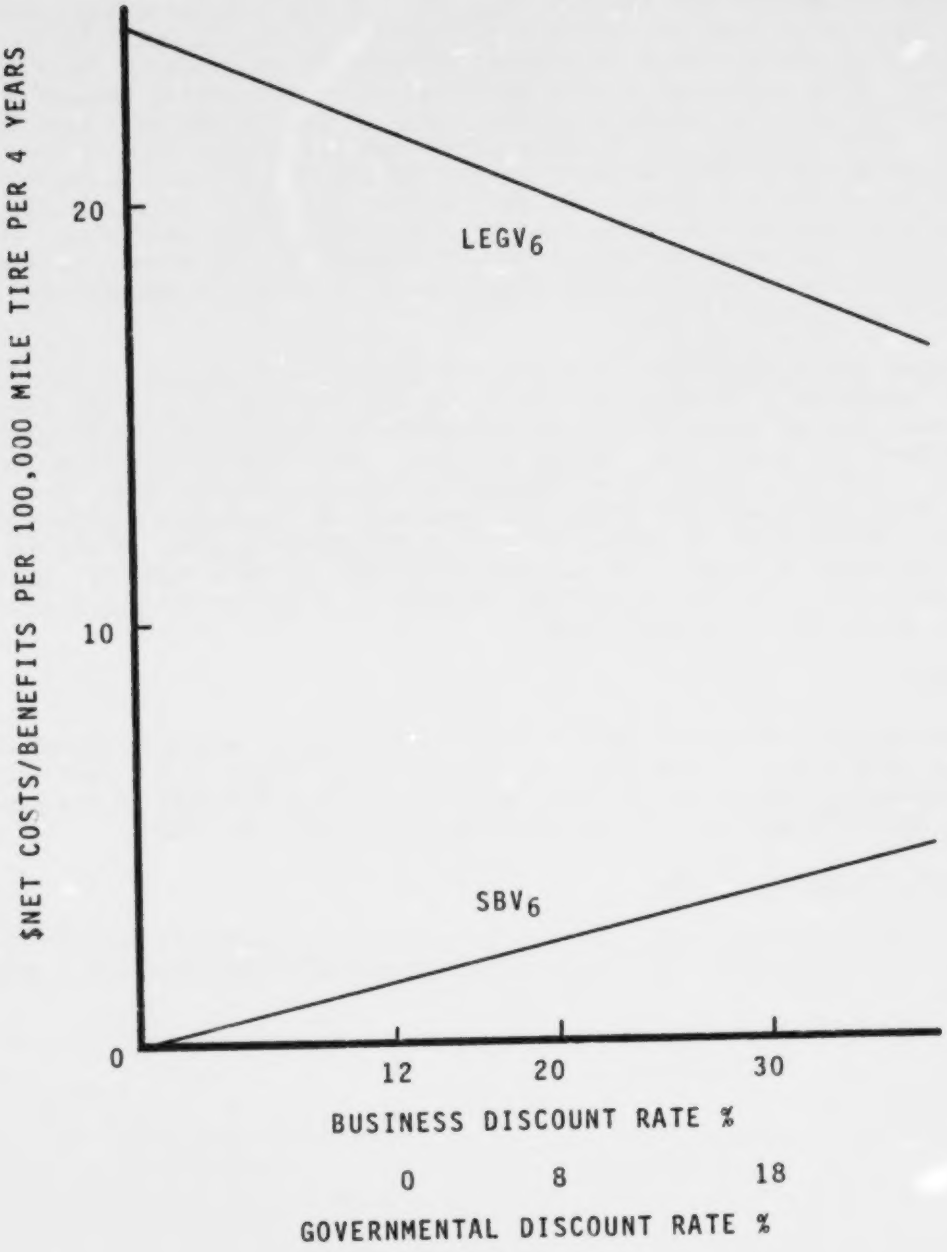

Figure 6. Discount rate versus 100,000 mile tire values.

Figure 5 indicates that, given 100,000 mile tire production costs of $29.71 and a discount rate of twenty percent, a 100,000 mile tire price greater than $100 is needed in order that 100,000 mile tires can be an attractive alternative for the tire industry. At the $100 price there are substantial social benefits. The social benefits of the 100,000 mile tire decrease by 13 percent for a 100 percent increase in the price of the 100,000 mile tire. This represents a relatively inelastic relationship between price and social value. The standard business value of the 100,000 mile tire increases, ceteris paribus, by 60 percent for each 100 percent increase in the selling price. At a price of $100 for the 100,000 mile tires, substantial bene benefits exist for both society and for the tire industry. This price is not unworkable as 100,000 mile tires have the seven substantial advantages, discussed above, upon which to build a marketing campaign, and since a preliminary consumer survey has indicated high consumer interest in 100,000 mile tires even at this price.

Figure 6 indicates that, at a price of $107 and a production cost of $29.71, 100,000 mile tires are attractive to the tire industry at any discount rate; the net value of 100,000 mile tires is positive no matter what the discount rate used at this price and cost. At a lower price, undoubtedly, there is a minimum discount rate required to make the tires viable. The social value of 100,000 mile tires decreases with an increasing discount rate and yet is substantial, in excess of $15 per 100,000 mile tire, at any discount rate below 40 percent for business decisions and 28 percent for governmental decisions. In TIREC a business discount rate twelve percent higher than the governmental rate was used.

RETREADING

Retreading is obviously technically feasible and an economically viable business proposition; consequently we do not discuss these as was done above for 100,000 mile tires. We discuss, instead, the pros and cons of retreading and the costs and benefits of retreading determined by TIREC.

Advantages and Disadvantages

Retreading is recycling. In tire solid waste management it should be recognized that retreading is a prominent management alternative for several reasons:

LIST 1

ADVANTAGES OF RETREADING

- Retreading conserves natural resources; it reuses tire carcasses. Retreading provides several years of continued primary use of a tire and, later, salvage by any of the several methods proposed for tire resource recovery. Retreading decreases the rate of usage of oil and other resources used in manufacturing new tires.
- Retreading provides economical service to consumers. The average cost of a new passenger car tire is $37; the average cost of a retread is $18. Retreads can be built to provide the same service life as a new tire.
- Retreading provides jobs. Any increase in the number of tires retreaded will require labor and materials; a commensurate increase in the number of jobs, an increase in employment, will also occur with increased retreading.
- Retreading decreases the rate of public tire solid waste disposal costs required. Fewer tires remain to be disposed of each year with increased retreading. Consequently smaller investment and operating costs for tire disposal facilities are required.
- Retreading enhances environmental quality, the quality of the physical environment. The larger the number of tires retreaded, the less land or air that is needed as a disposal sink, and, consequently, the higher the level of environmental quality.
- Retreading is an obviously viable business alternative that can operate based upon its own merit to provide profits to private entrepreneurs; it does not require governmental subsidy or operation.

These many favorable aspects of Retreading lead one to wonder, "Why isn't retreading promoted and increased in extent?". Again several reasons can be identified:

LIST 2

FACTORS LIMITING RETREADING

- Retreading has been thought of as only an interim solution; the tire still remains to be disposed of at a later date.
- The attitudes of tire manufacturers and dealers toward retreading do not favor a dramatic increase in the number of tires retreaded.
- Retreaded tires have been regarded by the public as "of dubious safety". Chunks of retreaded tires are constantly seen along highways.
- The thousands of different tire sizes, shapes, and types produced by new tire manufacturers have thwarted increased retreading because of the costs of maintaining a large inventory of molds and other retreading equipment needed to process the variety.
- An adequate inventory of carcasses suitable for retreading has not been generally available.
- Retreaders have not made their objective to, "Produce the highest quality retread possible". Instead the objective has been to provide an adequate retread at a lower cost.
- Retreaders have not marketed their product to the best extent possible.

It is a fact that retreading is different than resource recovery; retreading is a solid waste decreasing rather than residue handling process. Still retreading avoids solid waste operating costs and avoids costly investments in tire solid waste processing facilities. It is a very valuable part of the solid waste tire system as demonstrated by the net cost/benefits determined in this research.

We examine these costs and benefits in Table 8; the other factors limiting retreading are then briefly discussed and some ideas which may assist in eliminating the limits are presented.

TABLE 8. THE BENEFITS AND COSTS OF RETREADING

SBV_5	SBV_{5m}	$LEGV_5$	Benefits
-$34.15	$18.82	-$34.15	B_{51} Product value and decreased waste
-	-	$47.28	B_{52} Consumer costs avoided
-	-	$ 1.61	B_{53} Corporate profit tax transfers
-	-	$ .60	B_{54} Physical environment preservation
-	-	$ 5.86	B_{55} Materials conservation
-$34.15	$18.82	$21.20	Total benefits
			Costs
$ 1.08	$ 1.08	$ 1.08	C_{51} Tire collection and shredding
-$11.98	$ 9.52	-$11.98	C_{52} Production and solid waste
-	$ 1.90	-	C_{53} Administrative and marketing
$ 1.61	$ .16	$ 1.61	C_{54} Corporate profits taxes
-	-	$ 2.68	C_{55} Job gains and losses
-$ 9.29	$12.66	-$ 6.49	Total costs
-$24.86	$ 6.16	$27.69	Benefits minus costs

Retreading: An Interim Solution?

An Integrated Industry View of Retreading

SBV_5 indicates the value of a retreaded tire as seen from an integrated tire industry viewpoint. Retreaded tires are substitutes for cheap new tires; we valued the new tires at $52 each. This was meant to be a value for a cheap new steel belted radial tire. A retreaded tire sold in lieu of the new radial decreases the revenues of the seller by $34.15; this is an opportunity cost to a tire dealer.

Retreaded tires are very cheap to produce, however; as compared to a new steel belted radial tire, retreads are $11.98 cheaper. The difference in corporate profits taxes between the cheap new and the retreaded tire is $1.61. The tire collection costs for retreading are $1.08. These factors together favor the sale of the new steel belted radial tires by a figure of $24.86 per tire.

We believe that it is important to retreading that it be recognized that increased retreading is not viewed by new tire dealers as being beneficial to the tire industry. To a retreader who is not a new tire seller increased retreading is an objective. From the integrated viewpoint of a new tire dealer who is also a retreader, retread sales are not as valued as are new tire sales. From a tire dealers viewpoint too much retreading would cut out too many new tire sales. For a tire manufacturer, too much retreading would lower the demand for new tires and would decrease production needs, and profits. To dramatically increase the extent of retreading, these attitudes of manufacturers and dealers must be changed; then manufacturers and dealers will find, perhaps design changes and profit structure which make retreading total profits more competitive with new tires. This may be accomplished by (1) education, (2) government regulation, and/or (3) the actions of a strong independent organization of retreaders.

A Retreaders Viewpoint On Value

The SBV_{5m} value of Table 8, \$6.16 per retreaded tire, is a representation of the profits on a retreaded steel belted radial tire excluding the comparison and reference to a cheap new steel belted radial tire. There is no limit to the number of tires that a retreader who is only a retreader and not a new tire dealer wants to sell. \$18.82 revenues, on the average, are made on each sale and only \$12.66 in costs are incurred. The profit per retreaded tire is a fine incentive to increase the extent of retreading from a retreaders viewpoint.

Retreading: Social Value

Our representation of the social public value of retreading includes all of the costs and benefits: the tire industry costs described above, a \$34.15 net opportunity cost (net benefits of decreased solid waste handling costs) for the new tire not sold due to a substituted retread, the \$1.08 tire collection cost, and the \$1.61 cost of increased profits taxes, are included in $LEGV_5$ of Table 8. The \$2.68 net cost per retreaded tire of decreased employment is included. There are benefits of retreading that overwhelm even these high costs, however. Each retreaded steel belted radial tire avoids \$47.28 in consumer costs each four years when compared to the cost of a new steel belted radial tire. (Had we used the \$52 price, instead of \$65.50, this benefit would have been \$34 per retreaded tire.) Each retreaded tire provides a \$11.98 benefit of decreased, or smaller, production costs than a new radial. The \$1.61 increase in corporate profits taxes paid by retreaders is paid to the public treasury and, here, is recorded as a benefit. \$.60 per tire in benefits of avoiding use of the physical environment as a tire disposal sink are realized, and \$5.86 worth of tire building materials are conserved. The benefits of retreading are significantly higher than the costs; \$27.69 worth of net benefits (\$14.41 if the \$34 consumer cost benefit is used). Retreading, from a public viewpoint is a highly valuable industry, many orders of magnitude more valuable than pyrolysis, tire incineration, or landfill.

This measure, $LEGV_5$, of value includes, with equal weight, benefits and costs to tire manufacturers, tire dealers, retreaders, consumers and the public good. It is a comprehensive representation of value.

We include this cost benefit analysis in response to the argument that "retreading is not a solution to the waste tire problem - that a retreaded tire must be disposed of some time later". We included the cost of disposal of the solid waste tires, on a cost per retreaded tire per four year basis, in the retreading processing cost, C_{52}, of the cost benefit analysis. This allows the comparison of retreading, as a solid waste management alternative, to tire resource recovery methods proposed. This representation is one of a final tire solid waste solution that includes retreading as a process component. Retreading is a most important concept, technique, and industry for tire solid waste management.

Safety of Retreaded Tires

The second factor that we see as a limit to retreading is public perceptions of the safety of retreaded tires. It is a fact that retreaded tires are safer than generally thought. According to Rain's, in a survey of tire scraps found along highways, almost half of the tire rubber scraps are from new tires. It seems likely that the public assumes that all scraps of tire seen along highways are from retreads, when in fact the survey indicates that this is not the case. It should be noted, however, that retreads have a higher rate of tread separation per tire than do new tires. This note is based upon the equal proportions of new and retread scraps found by the survey and the knowledge that fewer retreads are on the roads than are new tires. Still retreads are probably safer than is generally assumed.

Retreaded tires can be safer yet if consumers are educated to know the safe limits in terms of safely allowable distances and speeds associated with current retreads and new tire designs such as the tire within a tire design are generally implemented. In this design, if there were a tire failure, another tire built inside the first would safely take over the tire functions. Many more tires could be retreaded and sold if the tire within a tire design were generally implemented by new tire manufacturers. The spare tire might also be eliminated.

The Tire Size/Shape Limit

There are, perhaps, two to three thousand different types, sizes, and brand names of tires. A retreader must have equipment to fit the tires which he will retread; he must have an inventory of molds of many sizes and types. To the extent that standardization and limitation on the number of tire sizes and shapes would be implemented, the number of worn tires retreaded could be increased.

The limitation placed upon retreading by the variety of tires produced has been relaxed to some extent by the recent Supreme Court decision which requires more standardization in manufacture and labelling of tires. It may be that even more standardization of tires is desirable if legislators and tire processors find the benefits of retreading warrent redesign of new tires so as to increase retreadability.

The Limit On Suitable Carcasses

Retreaders feel limited by the supply of worn tire carcasses available which are suited for retreading. This limit is closely associated with the size/shape limitation and would be alleviated by more standardization. In addition, tire manufacturers could, perhaps, design tires that would be annoying to ride on after the tread depth decreased toward a point near the minimum level suitable to retreading. Consumers would, in this situation, be inclined to retread or sell their tires while in a reasonable condition and, consequently, the number of tires retreaded could be substantially increased.

Quality Control For Retreads

Retreaders have available as materials several levels of quality; the usual tread rubber level used on retreads is not the top quality. With the best quality and workmanship a retread service life equal to the new tire's life may be obtained. This emphasis on quality could promote an increase in the extent of retreading.

Standardization, described above, would help to improve retread quality since there would be less inclination for a retreader to try to fit a carcass into a mold which is not exactly the right size.

New equipment has been developed which enables better inspection of tire carcasses for defects. This equipment could be utilized to a greater extent to increase retreading.

Statistical quality control procedures, long used in other industries, may be more and more utilized to control processes, materials, and the number of defects in completed production batches. Statistics may be used to improve public perceptions of the retread industry with the advertising of policies such as "99.7% (virtually 100%) of our first level retreads pass inspections for: (1) casing soundness, and (2) having been built according to the highest production standards".

More consumers might be lured to bring their own tires in for retreading; these tires would be of known quality and safeness to the consumer, and they could be retreaded with top quality tread rubber and other materials on equipment and with materials designed to exactly match the tires. Quality control over labor and equipment might be tightened up. The resultant product, with good marketing communication, could be sold in larger numbers than ever before - with the consumer, society, and the retreader all better off. To the extent that new manufacturers are, in addition, retreaders, new tire manufacturers would also be better off.

Marketing Retreads

Retreaders have not produced and marketed their product to the extent possible since it has not been pointed out that retreads provide the conservation, decreased consumer cost, jobs, decreased public costs, and environmental quality benefits quantified in Table 7. A marketing campaign based upon these factors and on safety would seem to promise great benefits for the retreading industry.

All of the above considerations point towards a conclusion that there can and should be an increase in the extent of retreading in future years. *To the extent that retreaded tires would still be limited in speed* and distance applications - and as an alternative of similar benefits - new tires designed to provide vastly increased management alternative.

TIRE ASPHALT RUBBER

Still a method for processing solid waste tires, after retreading, is needed. Tire asphalt rubber seems destined to fill this need.

Worn tire rubber recovered by cryogenics and mixed with asphalt in the proportions 25 percent rubber and 75 percent asphalt is useful in road repairs. Tire asphalt rubber repair projects have been carried out since the late 1960s in Arizona and have been carried out recently in California and other states. A four year Environmental Protection Agency Project to document experience with the tire asphalt rubber repairs is in process and will be completed in 1981. A detailed look at tire asphalt rubber is provided in Appendix D.

Costs and Benefits

Table 9 lists the costs and benefits of resource recovery management alternative, tire asphalt rubber. As a business proposition asphalt rubber is not economical; each tire processed by cryogenics for use in asphalt rubber results in $1.19 loss.

The rubber used for current tire asphalt rubber projects is not subjected to cryogenics; it is tread rubber buffed from worn tires, and the processing costs are lower than the $1 per tire cost of cryogenics. Consequently, for companies participating in this process it is an almost break even process. The current process does not dispose of waste tires, however. Cryogenics is needed in order that the process may be a waste management alternative.

The attraction of the asphalt rubber process is the huge public avoided cost benefits which accrue to highway repair agencies. Should the government, in accordance with the $38.69 consumer road repair "cost avoided" benefit, decide to implement the tire asphalt rubber alternative in large scale, the selling price for recovered tire rubber, included in B_{11}, would undoubtedly increase; tire asphalt rubber in this situation would become an economical business proposition. The current operators of this process are, undoubtedly, planning that this will occur.

The social benefits of tire asphalt rubber are highly significant. The value of the rubber recovered from tires, together with the value of the solid waste tire costs avoided, is $1.15; each tire provides $38.69 worth of highway repair costs avoided; $1.19 worth of the use of the physical environment is avoided for each tire processed; and finally $5 worth of highway repair materials are conserved by the process. The total of these benefits is $46.38.

TABLE 9. TIRE ASPHALT RUBBER BENEFITS AND COSTS

SBV_1	$LEGV_1$	
		Benefits
$ 1.15	$ 1.15	B_{11} Product value and decreased waste
-	$38.69	B_{12} Consumer costs avoided
-	-	B_{13} Corporate profits tax transfers
-	$ 1.19	B_{14} Physical environment preservation
-	$ 5.00	B_{15} Conservation of materials
$ 1.15	$46.38	Totals
		Costs
$ 1.14	$ 1.14	C_{11} Tire collection and shredding
$ 1.00*	$11.42	C_{12} Processing and solid waste
$ .20	$ 1.71	C_{13} Administration and marketing
-	-	C_{14} Corporate profits taxes
-	$ .48	C_{15} Job gains and losses
$ 2.34	$14.75	Totals
-$ 1.19	$31.37	Benefits minus costs

* This figure is the cost per tire for cryogenics; it is not calculated by TIREC.

Each tire processed by cryogenics costs $1.14 to collect. Processing costs per solid waste tire are a high $11.42 since, to include the benefits of road repair costs avoided each four years we must also include the costs of application of tire asphalt rubber to highways. Administrative and marketing costs total $1.71. Finally the tire asphalt rubber alternative creates jobs; the asphalt rubber additive is an additional step in road repairs. On the other hand it delays repairs and thus avoids or eliminates jobs. More jobs are eliminated each four years than are created. The net jobs effect is a job loss, per solid waste tire per four years, of $.48. The total of all of the road repair costs is $14.75.

The net benefits of the road repair alternative are $31.37 per tire processed. This is the largest net benefit of any alternative studied. This value is eighteen times greater than pyrolysis, forty-eight times greater than tire incineration, and 284 times as great as landfill. When all of the costs and benefits are included in the analysis, tire asphalt rubber is the best tire solid waste management alternative of all.

PARAMETRIC ANALYSIS: TIRE ASPHALT RUBBER

The high values determined for tire asphalt rubber might have been caused by any of the factors used in comparison: (1) the conventional road repair frequency, (2) conventional road repair costs; or (3) the cost of applying tire asphalt rubber. We examined variations in each of these factors.

Figure 7 indicates that the tire asphalt rubber value (Curve AC) is non linear and highly sensitive to the road repair frequency for repair intervals greater than five years. Even at a nine year repair interval, however, the tire asphalt rubber alternative exhibits substantial net benefits, $12. Consequently, we do not find the road repair interval of 3.33 years, used in our basic analysis, to be misleading; the high value exists even with longer frequencies between repairs.

Figure 8 demonstrates the affect of the dollar value used to represent conventional road repair costs upon the $LEGV_1$ value of tire asphalt rubber. We represented the tire asphalt rubber costs as $8661 per block. Figure 8 shows how the asphalt rubber value varies in comparison. Conventional road repair costs would have to be around $4000 per 3733 square yard city block, or the difference between asphalt rubber and conventional repair costs would have to be $4000 before the social value of tire asphalt rubber dropped to the level of the resource recovery alternatives. This information lends support to the conclusion regarding the desirability of the asphalt rubber alternative.

Figure 9 demonstrates the variation of the social value of tire asphalt rubber with the cost per square yard of road repaired by the process. In our basic analysis, we used the $1.75 per square yard cost of application of tire asphalt rubber. This represented the 1/4 inch rubber covering only, as our processing cost. The 1/4 inch covering, a seal coat, has been applied without asphalt cover with success in avoiding road repairs; the asphalt cover just makes the road smoother. Had the entire cost of asphalt and asphalt rubber, $2.32 per square yard, been used to represent this cost, the social value would have dropped substantially, to near zero; the value of the tire asphalt rubber alternative is somewhat sensitive to the cost per square yard of tire asphalt rubber. A forty-six percent decrease in value accrues to a 100 percent increase in the cost per square yard of application of tire asphalt rubber. At any reasonable cost for tire asphalt rubber, however, the social value is in excess of the other tire resource recovery alternative studied.

OTHER RESOURCE RECOVERY ALTERNATIVES

Pyrolysis, landfill, and tire incineration in specially designed incinerators are all losing business propositions; the tire industry will have to be prodded to implement these in large scale. These are not without social merit however; they decrease the use of the physical environment by a value of $1.19 per tire processed. Incineration and pyrolysis conserve on the use of energy and materials. The value of these effects is $.53 and $.96 per

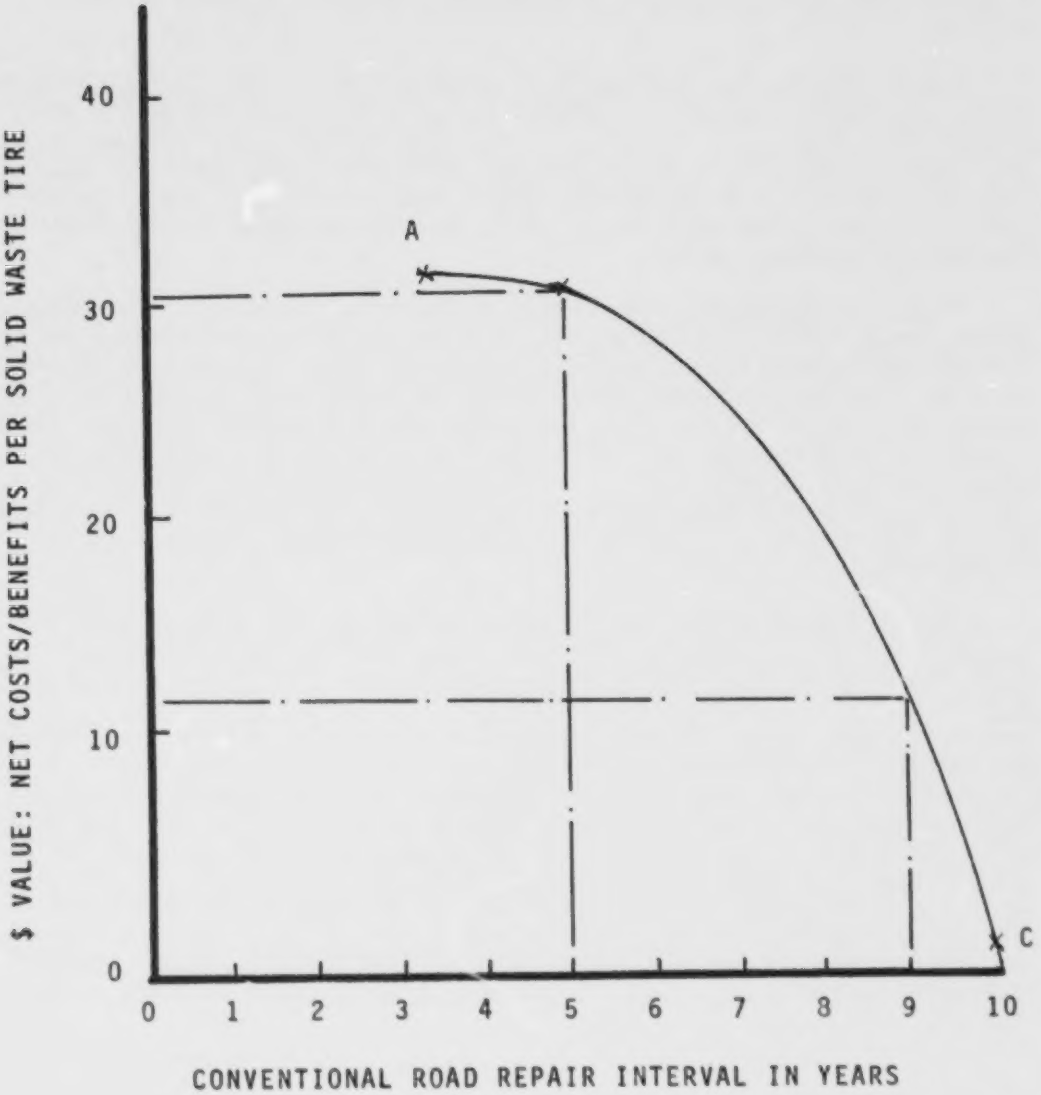

Figure 7. Tire asphalt rubber value versus conventional road repair frequency.

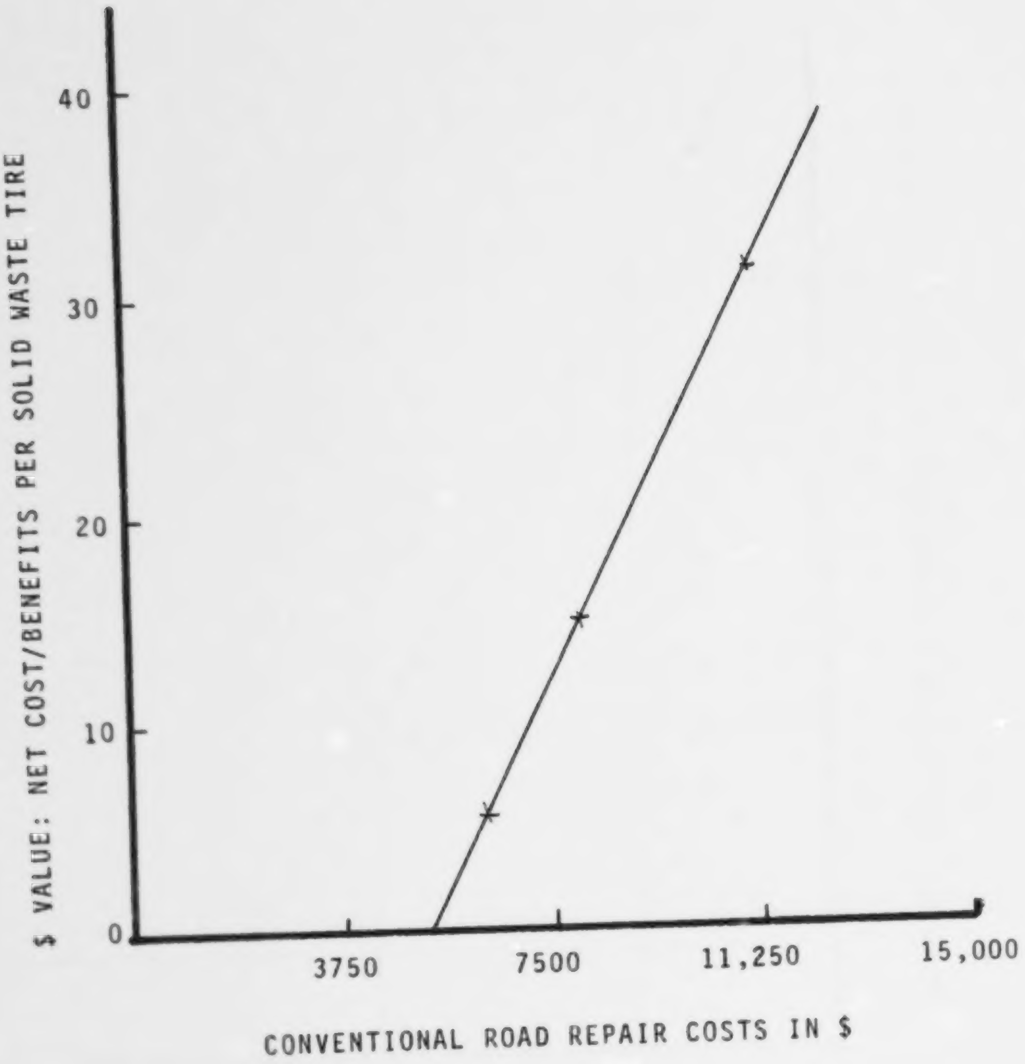

Figure 8. Tire asphalt rubber value versus conventional road repair costs.

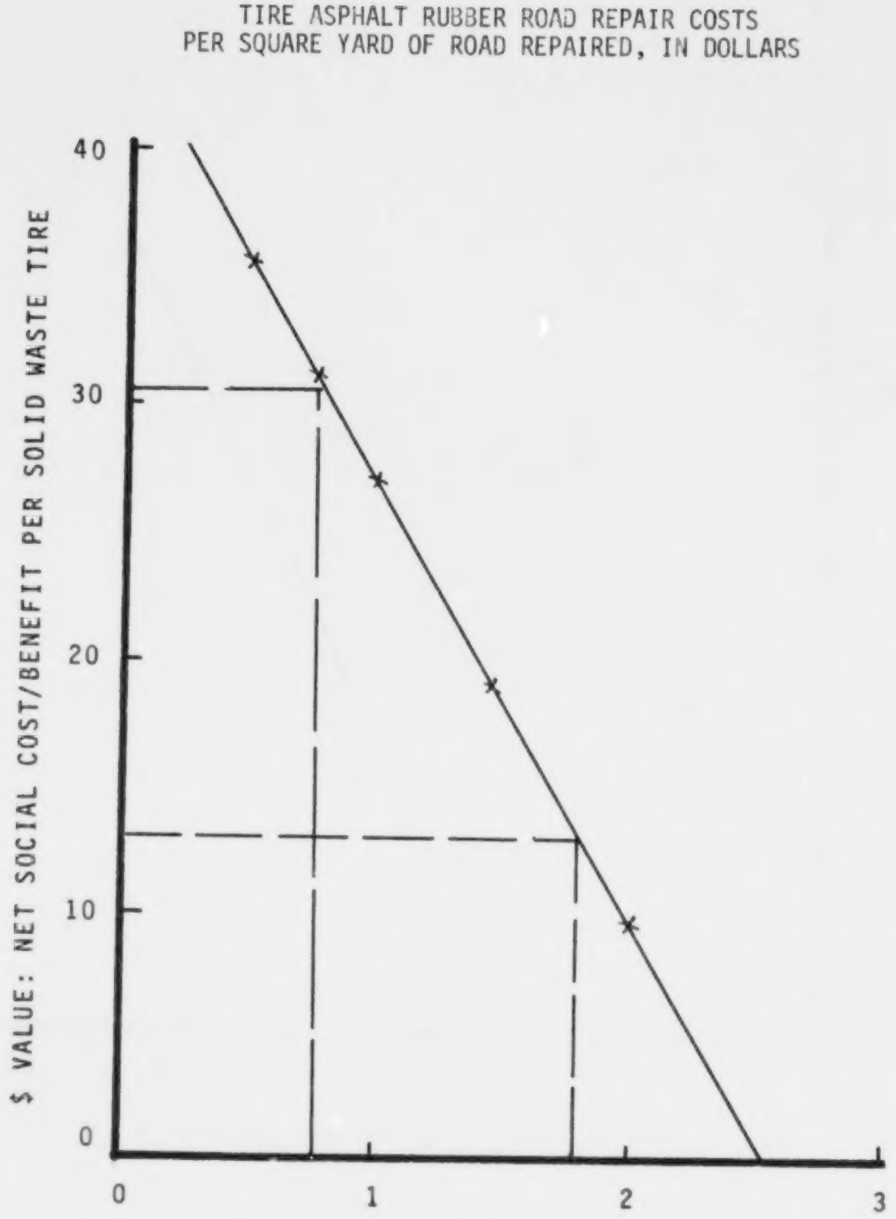

Figure 9. Tire asphalt rubber: social value versus cost.

tire processed, respectively. In addition landfill, incineration, and pyrolysis create jobs. The value of these jobs is $.03, $.16, and $.29 per tire processed. These alternatives are not able to compete with retreading, 100,000 mile tires, or tire asphalt rubber since they do not exhibit any benefits of a large scale.

LIMITS ON 100,000 MILE TIRES, RETREADING, AND TIRE ASPHALT RUBBER

The concept central to our analysis of 100,000 mile tires is that they can be a viable profitable business venture. Another approach to implementation of the 100,000 mile tire idea would be that such tires be required by federal product standards; 100,000 mile tires could be required on all new vehicles sold. In this situation the tire production volume, and subsequently, the tire solid waste volume, would fall to the level of the number of new cars produced each year. For 1978 this figure should represent about 40,000,000 to 50,000,000 tires per year. It is not inconceivable that those 40,000,000 to 50,000,000 tires per year could be retreaded. For an average life of a vehicle of ten years, vehicles use after ten years of age would provide a need for these retreaded tires. Eventually, however, 40,000,000 to 50,000,000 tires per year will require some final type of processing. Cryogenics with use of the rubber recovered in asphalt for use in road repairs can fill this need with substantial benefits to society. In fact it seems that cryogenics with tire asphalt rubber road repairs could process all or the 200,000,000 solid waste tires currently generated in the United States (See Appendix D) if necessary. These three alternatives are compatible and should form the basis of tires system management.

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APPENDIX A

BENEFITS AND COSTS: SYMBOLIC DEFINITIONS

The scope of the factors which we investigated was identified in Table 1. The benefits and costs which were determined to exist from among these factors are symbolically modeled in this section.

PRODUCT VALUE AND DECREASED WASTE BENEFITS (B_{11}- B_{61})

The product value and decreased wastes benefits are the sum, for each alternative, of the values determined by (1) the product value models, and (2) the decreased waste model which are discussed in separate sections below.

Product Value Benefits (PV_i)

The symbolic definitions used in calculating product value benefits are displayed in Table A-1. Product values were defined to include:

- -Sales prices for shredded rubber, usable land, energy, and materials including carbon, oil, and steel
- -Incremental sales revenues or losses as compared to new 40000 mile tires with which retreads and 100,000 mile tires compete
- -Salvage values for tire carcasses processed by Cryogenics, after retreaded or 100,000 mile service life is completed
- -Interest on funds gained or lost in the tradeoffs suggested by the waste reduction alternatives
- -Discounting

Decreased Waste Benefits (WA_i)

Each worn tire processed by a recovery method eliminates, forever, the administrative and processing costs that would have otherwise been necessary should that tire have been disposed of by landfill.. The waste decreasing methods avoid tire solid waste costs and, in addition, can eliminate them at a later date through resource recovery. We measure only the portion of the costs avoided here. The recovery methods avoid only processing and administrative costs while the waste decreasing methods eliminate a portion of all of the tire solid waste handling costs. The models which we used to represent are given in Table A-2:

LIST A-1

DEFINITIONS TO ACCOMPANY TABLE A-1

C_g = cost per solid waste tire for processing by Cryogenics

D_c = pounds of Carbon recoverable from one solid waste tire by Pyrolysis

D_o = barrels of oil recoverable from one solid waste tire by Pyrolysis

D_s = tons of scrap steel obtainable from one solid waste tire by Pyrolysis

H_m = additional materials needed for a 100,000 mile tire; a decimal fraction

I_d = interest and discount rate for business analysis

N_a = number of solid waste tires needed to fill one acre of landfill to a depth of six feet; calculated at 1 cubic foot per tire

P_a = price per acre for land reclaimed by landfill

P_c = selling price per pound for recovered Carbon

P_g = price per tire processed by Cryogenics and sold in bags as granules

P_h = selling price for a 100,000 mile tire

P_o = selling price per barrel for recovered oil

P_r = selling price for a retreaded steel belted radial tire

P_s = selling price per ton for scrap steel

P_t = price per ton for coal

$P_\star$ = selling price for a new 40,000 mile steel belted radial tire

R_p = proportion of a worn tire that is rubber

U_c = BTU heat value per pound of coal

U_r = BTU heat value per pound of worn tire rubber

W_t = average weight of a worn tire

TABLE A-1: PRODUCT VALUES. SYMBOLIC DEFINITIONS

Road Repairs: Product Value Model 1

$$PV_1 = P_g - C_g + P_s D_s$$

PV_1 = the net profit from Cryogenics, plus the revenues from the steel recovered, per solid waste tire

Landfill: Product Value Model 2

$$PV_2 = \frac{P_a}{N_a} = \frac{P_a}{261360}$$

PV_2 = the sales price for reclaimed land in a landfill six feet deep, per solid waste tire

Incineration/Energy: Product Value Model 3

$$PV_3 = \frac{P_t U_r W_t R_p}{2000\ U_c}$$

PV_3 = the sales value of the BTU's of heat value produced by a solid waste tire, valued at the price of coal

Pyrolysis: Product Value Model 4

$$PV_4 = D_c P_c + D_o P_o + D_s P_s$$

PV_4 = the sales revenues from recovered carbon, oil, and steel respectively

Retreading: Product Value Models 5 & 5m

$$PV_5 = \frac{(P_r - .8P_\star)}{1} + \frac{(P_g - C_g + P_s D_s)}{(1 + I_d)^{Y_\star}}$$

PV_5 = the difference in revenues between a retreaded and its new tire competitor, plus the salvage value of the worn tire carcass after one retreading

PV_{5m} = the term "$.8P_\star$" is removed from the model according to this modified definition.

Table A-1 (continued)

100,000 Mile Tires: Product Value Models 6 & 6m

$$PV_6 = \Bigg[P_h\left(1 + \frac{1}{(1+I_d)^{10}}\right) + (P_g - C_g + P_s D_s)\left(\frac{1}{(1+I_d)^{10}} + \frac{1}{(1+I_d)^{20}}\right)(1 + H_m)$$

$$- P_\star\left(1 + \frac{1}{(1+I_d)^{4}} + \frac{1}{(1+I_d)^{8}} + \frac{1}{(1+I_d)^{12}} + \frac{1}{(1+I_d)^{16}}\right)$$

$$-(P_g - C_g + P_s D_s)\left(\frac{1}{(1+I_d)^{4}} + \frac{1}{(1+I_d)^{8}} + \frac{1}{(1+I_d)^{12}} + \frac{1}{(1+I_d)^{16}} + \frac{1}{(1+I_d)^{20}}\right)\Bigg]$$

$$\cdot \frac{Y_\star}{2Y_6}\left(1 + \left(\frac{(1+I_d)^{Y_\star}}{Y_\star/2} - 1\right)\right)$$

PV_6 = the discounted sales revenues from two 100,000 mile tires, one sold at present and the other at the end of year ten, plus the discounted values of two 100,000 mile tire carcasses salvaged by Cryogenics, minus the discounted values of the five current 40,000 mile tires replaced by the two 100,000 mile tires, minus the discounted value of five 40,000 mile worn carcasses processed by Cryogenics. This sum is multiplied by a fraction representing the ratio of the planning period of our study to the number of years included in the comparison of 100,000 and 40,000 tires (20 years above) to convert it to a rate per four years. Finally, the result of the calculations is multiplied times a term which adds in the average interest on the funds gained or lost by this tradeoff each four years.

PV_{6m} is a modified definition of PV_6 in which includes only the 100,000 mile tire revenues per four years.

$$PV_{6m} = P_h\left(1 + \frac{1}{(1+I_d)^{10}}\right)\left(\frac{Y_\star}{2Y_6}\right)$$

TABLE A-2. WASTE DECREASING MODELS

$$WA_i = C_L + K_L C_L \qquad \text{for } i = 1,2,3, \text{ and } 4$$

$$WA_i = \left(\frac{C_r S_p}{V} + C_a + C_b + C_u + C_h + C_c + C_L + K_L C_L \right)\left(1 - \frac{Y_\star}{Y_i}\right) \qquad \text{for } i = 5,6$$

LIST A-2
DEFINITIONS TO ACCOMPANY TABLE A-2

C_a = cost of grading a worn tire casing for possible reuse

C_b = batch collection costs per solid waste tire

C_d = cost of grinding a worn tire, shredding to a finer degree

C_c = cost of chopping (shredding) a worn steel belted radial tire

C_h = cost of handling a solid waste tire

C_L = landfill operating costs per tire

C_r = average monthly rental cost for a tire dealer

C_u = haul costs per tire, solid waste

K_L = administrative costs, a relatively low decimal fraction estimate

S_p = average proportion of a tire dealer's space used to store worn casings

V = average tire dealer's inventory of worn casings

Y_i = the lifetime, service life expected at a usage rate of 10000 miles per year, of a tire

$Y_\star$ = the service lifetime of a 40000 mile tire at a usage rate of 10,000 miles per year

SUMMARY: PRODUCT VALUE AND DECREASED WASTE BENEFITS (B_{11} - B_{61})

The product value and decreased solid waste benefits are the sums of the benefits described above:

$$B_{1i} = PV_i + WA_i \qquad i = 1,\ldots.,6$$

CONSUMER COSTS AVOIDED (B_{12} - B_{62})

The road repairs, retreading, and 100,000 mile tire alternative accrue benefits to consumers in terms of avoided costs; incineration, landfill, and Pyrolysis do not exhibit these benefits.

Three symbolic definitions of road repairs costs avoided (by public road repair agencies) benefits, each representing an alternative average frequency of road repairs, are given in Table A-3. List A-3 provides definitions of the symbols used in the Table.

TABLE A-3. CONSUMER COST AVOIDED MODELS

$$B_{12} = \left(\frac{C_{sp} + S_{ip}}{N_b} \right) \left(\frac{Y^*}{Y_6} \right)$$

B_{12}= the road repair costs avoided per solid waste tire processed plus the interest on the funds available by this avoidance; both are measured over a four year time period

Where: (for a three year repair interval)

$$C_{sp} = (R_c - C_{tra}) + \frac{R_c}{(1+I_g)^{3.33}} + \frac{R_c}{(1+I_g)^{6.66}}$$

$$S_{ip} = \frac{(R_c - C_{tra})(1+I_g)^{10} - 1}{(1 + I_g)^{10}} + \frac{R_c(1+I_g)^{6.66} - 1}{(1 + I_g)^{10}} + \frac{R_c(1+I_g)^{3.33} - 1}{(1 + I_g)^{10}}$$

Where: (for a five year repair interval)

$$C_{spml} = (R_c - C_{tra}) + \frac{R_c}{(1 + I_g)^5}$$

$$S_{ipml} = \frac{(R_c - C_{tra}) (1 + I_g)^{10} - 1}{(1 + I_g)^{10}} + \frac{R_c (1 + I_g)^5 - 1}{(1 + I_g)^{10}}$$

Table A-3 (continued)

Where: (for a ten year repair interval)

$$C_{spm2} = R_c - C_{tra}$$

$$S_{ipm2} = \frac{(R_c - C_{tra})\ (1 + I_g)^{10} - 1}{(\ 1 + I_g\ )^{10}}$$

And: $N_b = W_p P G A_b N$

LIST A-3
DEFINITIONS TO ACCOMPANY TABLE A-3

A_b = the area, in square yards, of a 3733 square yard Phoenix, Arizona, city block of road

C_{sp} = present value (\$) of the road repairs avoided each ten years; the subscripts, ml and m2, represent modified definitions 1 and 2

C_{tra} = tire asphalt rubber road repair costs for one 3733 sq.yd. city block

G = the application rate, in gallons per square yard, for asphalt rubber

I_g = interest and discounting rate for federal funds

N = the proportion of a solid waste tire that it takes to recover one pound of tire rubber asphalt additive

N_b = the number of solid waste tire carcasses used in repairing one 3733 square yard city block

P = the weight, in pounds per gallon, of tire asphalt rubber

R_c = the cost of conventional repairs to one city block of road

S_{ip} = present value (\$) of the interest earnable on C_{sp}; the subscripts, ml and m2, represent modified definitions 1 and 2

Y^* = years of service life of a 40,000 mile tire

Y_6 = years of service life of a 100,000 mile tire

W_p = the proportion, by weight, of tire asphalt rubber which is worn tire rubber

The waste decreasing strategies, at our best estimates of production costs and sales prices, exhibit substantial benefits to consumers in terms of the cost per year of tire services provided. These consumer costs avoided benefits were represented as the cost savings per four years achieved by using retreaded or 100,000 mile tires in lieu of 40,000 mile tires. These benefits are modelled in Table A-4.

TABLE A-4. CONSUMER COSTS AVOIDED BENEFITS MODELS

$$B_{52} = P_{\star} - \frac{M_{\star}P_r}{(M_5 - M_{\star})}$$

$$B_{62} = P_{\star} - \frac{M_{\star}P_h}{M_6}$$

LIST A-4
DEFINITIONS TO ACCOMPANY TABLE A-4

$P_{\star}$ = the average retail price of a 40,000 mile steel belted radial tire

P_h = the average retail price of a 100,000 mile tire

P_r = the average retail price of a retreaded steel belted radial tire

$M_{\star}$ = the average 1977 mileage of a new steel belted radial tire

M_5 = the total mileage obtained by a retreaded steel belted radial tire; this includes both original and retreaded mileage

M_6 = the average mileage obtained by a 100,000 mile tire: 100,000 miles

CORPORATE PROFITS TAX TRANSFER BENEFITS (B_{31} - B_{36})

In the event that any of the alternatives studied earn profits, corporate profits taxes would have to be paid. These taxes represent a cost to the tire businessman, but a benefit to society. The tax funds may be spent by governmental agencies for activities beneficial to society. Corporate profits tax benefits models as represented in this study are given in Table A-5.

TABLE A-5. CORPORATE PROFITS TAX BENEFIT MODELS

Resource Recovery	$B_{i3} = P_iT = \left(B_{i1} - (C_{i1} + C_{i2} + C_{i3}) \right) T$	$i=1,\ldots 4$
Retreading	$B_{53} = T\ (F_5P_r - K_rC_t) - T\ (F_\star\ (.8P_\star) - EXL)$	
100,000 Mile Tires	$B_{63} = T\ (F_6P_h - EXAV) \left(\frac{Y_\star}{Y_6} \right) - T(F_\star P_\star - EXAV)$	

LIST A-5
DEFINITIONS TO ACCOMPANY TABLE A-5

C_t = retreading production cost

EXAV = selling expenses for a 40,000 mile steel belted radial tire (average)

EXL = selling expenses for a 40,000 mile steel belted radial tire; low estimate

$F_\star$ = tire dealer's gross profit rate on the selling price for a 40,000 mile steel belted radial tire

F_5 = tire dealer's gross profit rate for a 40,000 mile retreaded tire

F_6 = tire seller's gross profit rate on selling price for 100,000 mile tire

K_r = decimal fraction representing administrative and marketing costs for a retreaded tire

$P_\star$ = sales price for a 40,000 mile new tire

P_i = corporate profits for recovery alternative "i"

P_h = sales price for a new 100,000 mile tire

P_r = sales price for a 40,000 mile retreaded tire

T = the corporate profits tax rate

$Y_\star$ = service lifr of a 40,000 mile tire

Y_6 = service life for a 100,000 mile tire

PHYSICAL ENVIRONMENT/AESTHETICS BENEFITS (B_{14} - B_{64})

Resource recovery, recycling, and source reduction are concepts designed to maintain quality of the physical environment. When a worn tire is littered, dumped, or improperly landfilled, it results in pollution and creates a less desirable environment. Resource recovery, recycling, and source reduction avoid this land pollution. The dollar value of maintaining quality of the physical environment, avoiding land pollution, may be represented as being equivalent to the costs which would be necessary to properly dispose of a tire; environmental quality can be measured! We used landfill costs as a surrogate for this purpose. (see Table A-6 and List A-6) The use of landfill costs was a rather conservative choice, however, since the physical environment, a shredded tire landfill, will never be truly natural.

TABLE A-6. QUALITY OF THE PHYSICAL ENVIRONMENT MODELS

$$B_{i4} = \frac{C_r S_p}{V} + C_a + C_b + C_u + C_h + C_c + C_L + K_L C_L \qquad i=1,..,4$$

Where B_{i4} equals the costs of storage,grading, batch collection, haul, handling, chopping, landfill operating costs, and landfill administrative costs

$$B_{54} = \frac{C_r S_p}{V} + C_a + C_b + C_u + C_h + C_c + C_L + K_L C_L \left(\frac{Y_*}{Y_5}\right)$$

Where B_{54} equals B_{14} adjusted to be a rate per four years; this includes both the original and retreaded life of the retreaded tire in Y_5

$$B_{64} = B_{14} \left(1 + \frac{1}{(1+I_g)^4} + \frac{1}{(1+I_g)^8} + \frac{1}{(1+I_g)^{12}} + \frac{1}{(1+I_g)^{16}}\right)$$

$$- (1+ H_m) \left(\frac{1}{(1+I_g)^{10}} + \frac{1}{(1+I_g)^{20}}\right) \left(\frac{Y_*}{2Y_6}\right)$$

Where B_{64} equals the difference in tire solid wastes costs between five conventional 40,000 mile tires and two 100,000 mile tires; the difference is adjusted to be a rate per four years

LIST A-6
DEFINITIONS TO ACCOMPANY TABLE A-6

B_{14} = the benefits to improved (maintained) quality of the physical environment attributable to a solid waste tire recovery process; specifically, the benefit in road repairs is used-this is equivalent to the benefit in landfill, B_{24} , which could have been used in the formula instead

C_a = the costs of grading a worn tire carcass for reuse

C_b = the batch collection costs per worn tire

C_c = the costs of chopping up (shredding) a solid waste tire

C_h = handling costs per solid waste tire

C_L = the landfill operating costs per solid waste tire

C_r = the average monthly rental cost for a tire dealer

C_u = the haul costs per solid waste tire

H_m = a decimal fraction representing the additional materials needed for a 100,000 mile tire

I_g = the discount/interest rate for governmental funds

K_L = a low administrative and marketing cost factor decimal fraction

S_p = the average proportion of a tire dealer's space used for storage of worn tire casings

V = the average inventory of worn tire casings held by a tire dealer

$Y_{\star}$ = the average years of service life of a 40,000 mile steel belted radial tire

Y_5 = the total service life of a retreaded steel belted radial tire, including both the original life and the retreaded life, in years

Y_6 = the service life , in years, of a 100,000 mile tire

It might be noted that retreading and 100,000 mile tires accrue these benefits due to decreases in the solid waste generation rate; they may still be recovered at a later date to provide a full set of environmental benefits as do the recovery alternatives. Since our study was organized to compare the alternatives as if they were mutually exclusive, we did not model this effect.

CONSERVATION BENEFITS (B_{15} - B_{65})

All of the alternatives studied, except for landfill, conserve resources. The road repairs with tire asphalt rubber alternative avoids the use of road repair materials; this effect was measured as a product value earlier. Tire asphalt rubber, in addition, may be compared to an alternative process which is designed to accomplish the same end, avoiding road repairs. Heater Scarification with Petroset is a viable alternative to tire asphalt rubber. (see Appendix D) We determined the conservation benefit per tire for tire asphalt rubber with respect to this process. This benefit (and other conservation benefits discussed below) is modelled in Table A-7 below.

TABLE A-7. CONSERVATION OF MATERIALS BENEFITS

$$B_{15} = \frac{C_e - C_s - C_f}{N_s}$$

$$B_{35} = \frac{P_t U_r W_t R_p}{2000\ U_c}$$

$$B_{45} = D_c P_c + D_o P_o + D_s P_s$$

$$B_{55} = R_\star (S_m + .3S_o) \left(1 - \frac{Y_\star}{Y_5}\right)$$

$$B_{65} = R_\star (S_m + .3S_o) \left(1 + \frac{1}{(1+I_g)^4} + \frac{1}{(1+I_g)^8} + \frac{1}{(1+I_g)^{12}} + \frac{1}{(1+I_g)^{16}}\right)$$

$$- H\ (S_m + .3S_o) \left(1 + \frac{1}{(1+I_g)^{10}}\right) \left(\frac{Y_\star}{2Y_6}\right)$$

LIST A-7

DEFINITIONS TO ACCOMPANY TABLE A-7

C_e = the cost per square yard for road repairs using heater scarification with Petroset

C_f = the average cost of ½ inch of asphalt concrete (ACFC) finishing coat in road repairs

C_s = the average cost of one inch of asphalt concrete in road repairs

D_c = the pounds of carbon obtainable from one solid waste tire using the Tosco Pyrolysis (Destructive Distillation) process

D_o = the barrels of recovered oil obtainable from one solid waste tire using the Tosco Pyrolysis (Destructive Distillation) process

D_s = the tons of scrap steel obtainable from one solid waste tire using the Tosco Pyrolysis (Destructive Distillation) process

H = the average production cost for a 100,000 mile steel belt radial tire

I_g = the discount/interest rate for governmental funds

N_s = the number of whole tires used in one square yard of tire asphalt rubber road repairs

P_c = the selling price per pound for recovered carbon

P_o = the selling price per barrel for recovered oil

P_s = the selling price per ton for recovered steel

P_t = the price per ton of coal

$R_\star$ = the average production cost for a 40,000 mile steel belted radial tire

R_p = the proportion of a worn tire which is rubber

S_m = the proportion of a tire manufacturer's average selling price per tire allocable to materials costs

S_o = the proportion of a tire manufacturer's average selling price per tire allocable to overhead

U_c = the heat value, in British Thermal Units (BTU), obtainable from a pound of coal

U_r = the heat value, in British Thermal Units (BTU), obtainable from one pound of solid waste tire rubber

W_t = the average weight, in pounds, of a solid waste tire

$Y_\star$ = the years of service life of a 40,000 mile steel belted radial tire

Y_6 = the years of service life of a 100,000 mile steel belted radial tire

Y_5 = the years of service life of a retreaded tire; including both the original equipment life and the retreaded life

Two alternatives, incineration with energy recovery and Pyrolysis, also conserve resources. Each tire incinerated to produce energy avoids the need for using a comparable amount of primary fuel. The formula for B_{35} of Table A-7 represents the value of this fuel conserved per solid waste tire. The formula for B_{45} represents the value of the carbon, oil, and steel conserved by reusing carbon, oil, and steel from solid waste tires. The conservation benefit of retreaded tires has been represented, in Table A-7, as the savings in materials and associated overhead each four years. The conservation benefit for 100,000 mile tires is slightly more complicated. We modelled this benefit as the discounted difference, per four years, between the materials used in five 40,000 mile steel belted radial tires and two 100,000 mile tires.

TIRE COLLECTION COSTS (C_{11} - C_{61})

Solid waste tire collection costs were defined to include the six separate costs indicated in Table A-8.

TABLE A-8. INVENTORY, HANDLING, SHREDDING, AND TRANSPORTATION COSTS

$$C_{i1} = \frac{C_r S_p}{V} + C_a + C_b + C_u + C_h + C_c \qquad i = 1,..,4$$

$$C_{i1} = \left(\frac{C_r S_p}{V} + C_a + C_b + C_u + C_h + C_c \right) \left(\frac{Y_\star}{Y_i} \right) \qquad i = 5,6$$

LIST A-8
DEFINITIONS TO ACCOMPANY TABLE A-8

C_a = the costs of grading a worn tire carcass for reuse

C_b = the costs of batch collection per worn tire

C_c = the costs of chopping up (shredding) a solid waste tire

C_h = handling costs per worn tire

C_r = the average monthly rental cost for a tire dealer

C_u = the haul costs per solid waste tire

S_p = the average proportion of a tire dealer's space used for storage of worn tire casings

V = the average inventory of worn tire casings held by a tire dealer

$Y_\star$ = the average number of years of service life of a 40,000 mile steel belted radial tire

Y_i = the average number of years of service life for retreaded or 100,000 mile tires; i=5 for total retreaded & OE life, i=6 for 100,000 mi. tire

Collection costs are represented as the sum of: (1) inventory holding costs associated with storage space rental, (2) grading costs of inspection and classification, (3) batch or micro-collection costs, (4) haul or macro-collection costs, (5) handling costs for loading and unloading, and (6) shredding or grinding costs. The solid waste decreasing alternatives, retreading and 100,000 mile tires, have their costs decreased by the ratio, Y_*/Y_i, since these decrease the quantities of solid wastes requiring collection each year.

PROCESSING COSTS (C_{12} - C_{62})

The resource recovery processing costs for landfill, Pyrolysis, and incineration were not symbolically modeled in this work, but rather were input to our calculations as data. The processing cost for road repairs was represented as the cost per solid waste tire for materials and for the application of tire asphalt rubber.

TABLE A-9. RECOVERY, SOLID WASTE, AND PRODUCTION PROCESSING COSTS.

$$C_{12} = \frac{R_r A_b}{N_b} = \frac{C_{tra}}{N_b}$$

$$C_{52} = C_t + \left(\frac{Y_*}{Y_5}\right) E$$

$$C_{62} = \left[H\left(1 + \frac{1}{(1+I_d)^{10}}\right) - \left(R\left(1 + \frac{1}{(1+I_d)^4} + \frac{1}{(1+I_d)^8} + \frac{1}{(1+I_d)^{12}} + \frac{1}{(1+I_d)^{16}}\right)\right)\right] \frac{Y^*(1+I_d)^{Y^*}}{2Y_6} + \frac{Y^*}{Y_6} E$$

The processing cost for retreading represents the cost of retreading a steel belted radial tire plus the cost of processing the tire solid wastes per tire retreaded that still remain each year. The processing cost for 100,000 mile tires represents the difference (and interest on the difference) in original equipment production costs between two 100,000 mile tires and five 40,000 mile tires. This difference has been discounted and adjusted to be a rate per the lifetime of the tire which is used as the reference for our cost and benefit measurements. The solid waste tire costs that remain each year with this waste decreasing alternative are then added.

Definitions of the symbols utilized in Table A-9 are given in List A-9.

LIST A-9
DEFINITIONS TO ACCOMPANY TABLE A-9

A_b = the area, in square yards, of a Phoenix Arizona city block: 560' X 60'

C_t = the cost of retreading a steel belted radial tire

C_{tra} = the costs of tire asphalt rubber repairs to a 560' X 60' city block

E = the costs of collection, handling, processin, and disposal for a solid waste tire

H = the average production cost for a 100,000 mile steel belted radial tire

I_d = the discount/interest rate used to represent privately invested capital

N_b = the number of solid waste tires needed for tire asphalt rubber repairs to a city block 560' X 60'

R = the average production cost for a 40,000 mile steel belted radial tire

R_r = the cost per square yard for materials and application of tire asphaly rubber

Y_* = the years of service life of a 40,000 mile steel belted radial tire

Y_5 = the years of service life of a retreaded tire including the original equipment and retreaded lives

Y_6 = the years of service life of a 100,000 mile tire

ADMINISTRATION AND MARKETING COSTS (C_{13} - C_{63})

Administrative and marketing costs, listed in Table A-10, were estimated as a percent of the processing costs. Administrative and marketing costs for 100,000 mile tires were negative; these were, in actuality, benefits in terms of decreased costs. 100,000 mile tires decrease production, administration, and marketing throughput volume; fewer salesmen and administrators are needed with this alternative.

TABLE A-10. ADMINISTRATION AND MARKETING COSTS MODELS

$$C_{i3} = K_i C_{12} \qquad i = 1,\ldots,6$$

LIST A-10
DEFINITIONS TO ACCOMPANY TABLE A-10

C_{12} = the processing costs for recovery, recycling, and 100,000 mile tires

K_i = administrative and marketing costs expressed as a decimal fraction

OPPORTUNITY COSTS: JOB GAINS AND LOSSES

This cost category was developed as a focus for discussion of the emotion packed costs and benefits associated with job losses and shifts and with the creation of new jobs. The production of 100,000 mile tires will, over a period of time, decrease the number of jobs in the tire industry; in the short run 100,000 mile tires increase employment. Retreaded tires can be substitutes for new tires. Increased retreading creates new retreading jobs, but decreases employment in the new tire production sector by a commensurate amount. Resource recovery, on the other hand, creates jobs. If the sole criterion for selection of a solid waste tire management strategy were the affects on employment then retreading and resource recovery seem to be especially attractive.

How can the value of a job be measured? If there is an appropriate way, it would be as follows. The importance of jobs is to the people who would, or do, hold the job. The measure of job value is the salary or wages paid for that job. Consequently, job gain benefits might be measured as the value of the increase in labor costs associated with an alternative. Job costs might be measured as the value of the labor wages and salaries lost as a result of implementation of one of the alternatives.

Symbolic models for job loss costs and job gains benefits (negative job loss costs) are given in Table A-11.

TABLE A-11. JOB GAINS AND LOSSES MODELS

$$C_{i5} = -O_L B_{i_1} \qquad i = 1,\ldots,4$$

$$C_{55} = S_L\ (.8R) - S_r C_t \qquad i = 5$$

$$C_{65} = \left((S_L + H_L)\ H - 2.5\ \ S_L R\right)\left(\frac{Y_*}{Y_6}\right)$$

The job cost/benefit for retreading is modeled as the difference between the labor value for a cheap new tire, the cheap new tire being priced at eighty percent of the cost of production of a new tire, and the labor value for production of a retreaded tire.

The job cost/benefit for 100,000 mile tires is represented as the difference between the labor value of one 100,000 mile tire and 2.5 steel belted radial 40,000 mile tires; this difference has been adjusted to be a rate per the lifetime of the reference tire.

LIST A-11

DEFINITIONS TO ACCOMPANY TABLE A-11

B_{i1} = the value of the product(s) produced by recovery, recycling by retreading, and 100,000 mile tires

C_t = the cost of retreading a steel belted radial tire

H = the average production cost for a 100,000 mile tire

H_L = a decimal fraction representing the increased labor needed for a 100,000 mile tire

O_L = the decimal fraction of resource recovery products value attributable to labor

R = the average production cost for a 40,000 mile steel belted radial tire

S_L = the proportion of a tire manufacturer's average selling price, per tire, allocable to labor costs

S_r = the fraction of a retreaded tires production cost attributable to labor

APPENDIX B

THE TIREC PROGRAM

Tirec I is a program developed in 1973 as part of the author's doctoral dissertation. Tirec I calculated the costs, benefits, and values ofr eight tire resource recovery alternatives; it conducted optimality and linear programming analyses in addition.

Tirec I was modified for this research to represent improved cost and benefit definitions and alternative optimality analyses. The program, Tirec II, is documented only by comments, (1) in the program itself, and (2) in this report. Tirec II allows for eight alternatives and yet studies only six alternatives. The alternatives studied are numbered differently in Tirec II than they are in this report. The alternative numbers used may be identified in Table B-1.

TABLE B-1. TIREC ALTERNATIVES IDENTIFICATION

Alternative	Alternative number		
	Tirec I	Tirec II	This Report
Incineration	1	1	3
Tire asphalt rubber	2	2	1
Roadbase aggregate	3	not used	not studied
Landfill	4	4	2
Destructive dist.	5	5	4
Retreading	6	6	5
38,000 mile tires	7	not used	not used
100,000 mile tires	8	8	6

The costs and benefits of the unused alternatives 3 and 7 of Tirec II were set equal to zero. No linear programming analysis was carried out in the Tirec II analysis although the storage spaces of Tirec I were left declared in the program in order that the linear programming subroutine could be emplaced as desired.

The calculation of SBV_{im} values is not carried out automatically by Tirec II; all other calculations are made by the program.

Tirec II is a working program specifically designed for tires research. It is not a general cost/benefit program. Tirec II is not designed to be efficient in terms of computer time used yet it requires only about six minutes total processing time on a IBM 370-148 computer using the PL1 optimizing compiler. The printing time (for about 100 pages) is additional.

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OPTIMIZING COMPILER

                    SOURCE LISTING

STMT

     |/* TIRES BENEFIT/COST PROCESSING & OPTIMIZATION ANALYSIS PROGRAM */
   1 |TIREC: PROCEDURE OPTIONS (MAIN);
   2 |DCL (M,N) FIXED BINARY;
     |
     |
     |
     |/* STORAGE SPACE ALLOCATION AND VARIABLE NAMING SECTION */
     |
     |
   3 |M=4; N=8;
   5 |DISSERT: BEGIN;
   6 |DCL (F,I,J,K,L,P,R,S,T,V) FIXED BINARY INIT (0);
   7 |DCL D FIXED DEC (9,2);
   8 |DCL A(M+1,0:N+M) FIXED DEC (15,3);
   9 |DCL C(0:N+M) FIXED DEC (15,3) INITIAL ((1+N+M) 0);
  10 |DCL (RATIO,THETA) FIXED DEC (15,3) INITIAL (0);
  11 |DCL B(M) FIXED BINARY;
  12 |DCL BENEFITS (8,5) FIXED DEC (15,3);
  13 |DCL COSTS(8,9) FIXED DEC (15,3);
  14 |DCL AV_DEALERS_MONTHLY_RENTAL FIXED DEC (10,2);
  15 |DCL GRADING_COSTS FIXED DEC (10,2);
  16 |DCL BATCH_COLLECTION_COSTS FIXED DEC (10,2);
  17 |DCL WORN_TIRE_STORAGE_PROPORTION FIXED DEC (10,2);
  18 |DCL (HAUL_COSTS,HANDLING_COSTS) FIXED DEC (10,2);
  19 |DCL (GRINDING_COSTS,CHOPPING_COSTS) FIXED DEC (10,2);
  20 |DCL WASTE_PROPORTION(N) FIXED DEC (10,2);
  21 |DCL TIRE_YEARS_LIFE(N) FIXED DEC (10,2);
  22 |DCL MILEAGE_USE_PER_YEAR FIXED DEC (10,2);
  23 |DCL TOTAL_MILEAGE_PER_TIRE(N) FIXED DEC (10,2);
  24 |DCL BELTED_BIAS_PROD_COST FIXED DEC (10,2);
  25 |DCL COST_INDEX FIXED DEC (10,2);
  26 |DCL DISCOUNT_RATE FIXED DEC (10,2);
  27 |DCL ONE_HUND_MI_TIRE_PROD_COST FIXED DEC (10,2);
  28 |DCL MATERIALS_PROPORTION FIXED DEC (10,2);
  29 |DCL ADMIN_MKTG_COST_FACTOR_LOW FIXED DEC (10,2);
  30 |DCL ADMIN_MKTG_COST_FACTOR_HIGH FIXED DEC (10,2);
  31 |DCL ADMIN_MKTG_COST_FACTOR_RETREADS FIXED DEC (10,2);
  32 |DCL ADMIN_MKT_COST_FACTOR_100000_MI FIXED DEC (10,2);
  33 |DCL TIRE_MILEAGE_PRICE_EQUIVALENT(N) FIXED DEC (10,2);
  34 |DCL AV_38000_MILE_TIRE_PRICE FIXED DEC (10,2);
  35 |DCL AV_100000_MILE_TIRE_PRICE FIXED DEC (10,2);
  36 |DCL INTERNAL_COSTS(N) FIXED DEC (10,2);
  37 |DCL COAL_PRICE_PER_TON FIXED DEC (10,2);
  38 |DCL POUNDS_PER_WASTE_TIRE FIXED DEC (10,2);
  39 |DCL LAND_PRICE_PER_ACRE FIXED (10,2);
  40 |DCL DESTRUCTIVE_DIST_PRODUCTS_PRICE FIXED DEC (10,2);
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  41   |DCL INTERNAL_VALUE(N) FIXED DEC (10,2);
  42   |DCL AV_RETREAD_TIRE_PRICE FIXED (10,2);
  43   |DCL TIRE_CARCASS_VALUE_PROPORTION FIXED DEC (10,2);
  44   |DCL SOCIAL_VALUES(N) FIXED DEC (10,2);
  45   |DCL VAL_LIMIT(M) FIXED DEC (10,2);
  46   |DCL HOLD FIXED DEC (15,3);
  47   |DCL QUANT FIXED DEC (15,3);
  48   |DCL WASTE_DECREASE_PT_PER_YEAR(N) FIXED DEC (10,2);
  49   |DCL ENVR_QUALITY_COSTS FIXED DEC (10,2);
  50   |DCL CORP_PROFIT_TAX_RATE FIXED DEC (15,3) INIT (0);
  51   |DCL TAXHOLD FIXED DEC (15,2);
  52   |DCL FIG FIXED DEC (10,2);
  53   |DCL CHK FIXED DEC (10,2);
  54   |DCL RADIAL_38S_PROD_COST FIXED DEC (10,2);
  55   |DCL SET(N) FIXED DEC (10,2);
  56   |DCL PROFIT_RATE(N) FIXED DEC (10,2) INIT ((N) 0);
  57   |DCL HEADING CHAR (100) INITIAL ('BEST VALUE COEFFICIENT ESTIMATES');
  58   |DCL PARAM CHAR (100) VARYING;
  59   |DCL PARAMVAL FIXED DEC (10,2) INITIAL (0);
  60   |DCL RET_PROC_COST FIXED DEC (10,2);
  61   |DCL WORK(9) FIXED DEC (15,3) INIT ((9) 0);
  62   |PARAM = ' ';
  63   |DCL SL FIXED DEC (5,3);
  64   |DCL SO FIXED DEC (5,3);
  65   |DCL HM FIXED DEC (5,3);
  66   |DCL DT FIXED DEC (5,3);
  67   |DCL DI FIXED DEC (5,3);
  68   |DCL DQ FIXED DEC (5,3);
  69   |DCL DD FIXED DEC (5,3);
  70   |DCL DW FIXED DEC (5,3);
  71   |DCL DS FIXED DEC (5,3);
  72   |DCL HD FIXED DEC (5,3);
  73   |DCL ID FIXED DEC (10,2);
  74   |DCL OL FIXED DEC (10,2);
  75   |DCL SR FIXED DEC (10,2);
  76   |DCL HL FIXED DEC (10,2);
  77   |DCL RB FIXED DEC (5,3);
  78   |DCL UW FIXED DEC (6,0);
  79   |DCL UL FIXED DEC (6,0);
  80   |DCL EXL FIXED DEC (10,2);
  81   |DCL EXAV FIXED DEC (10,2);
  82   |DCL DC FIXED DEC (10,2);
  83   |DCL PC FIXED DEC (10,2);
  84   |DCL CO FIXED DEC (10,3);
  85   |DCL PO FIXED DEC (10,2);
  86   |DCL DX FIXED DEC (10,3);
  87   |DCL PA FIXED DEC (10,2);
  88   |DCL TW FIXED DEC (10,2);
  89   |DCL PD FIXED DEC (10,2);
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  90  |DCL GA FIXED DEC (10,2);
  91  |DCL AB FIXED DEC (10,2);
  92  |DCL NT FIXED DEC (10,2);
  93  |DCL SIP FIXED DEC (10,2);
  94  |DCL CSP FIXED DEC (10,2);
  95  |DCL RC FIXED DEC (10,2);
  96  |DCL CTRA FIXED DEC (10,2);
  97  |DCL NB FIXED DEC (10,2);
  98  |DCL CE FIXED DEC (10,2);
  99  |DCL CS FIXED DEC (10,2);
 100  |DCL CF FIXED DEC (10,2);
 101  |DCL NS FIXED DEC (10,2);
 102  |DCL ROAD_REPAIR_COST FIXED DEC (6,2);
 103  |DCL CRYOGENICS_COST FIXED DEC (6,2);
 104  |DCL PRC FIXED DEC (6,2);
 105  |DCL CY FIXED DEC (6,2);
 106  |DCL RAMFLEX_PRICE FIXED DEC (10,2);
 107  |DCL RECPROC FIXED BINARY;
 108  |DCL AV_BELTED_BIAS_TIRE_PRICE FIXED DEC (10,2);
 109  |DCL RET_OPP_COST_TO_MANUFACTURERS FIXED DEC (10,2);
 110  |DCL ADMIN_MKTG_COST_FACTOR_38000_MI FIXED DEC (10,2);
 111  |DCL PLANT_SIZE_TPD FIXED DEC (10,2);
 112  |DCL CAPITAL_PTPC_CONVERSION_COSTS FIXED DEC (10,2);
 113  |DCL JTISV(N) FIXED DEC (15,3);
      |
      |
      |/*  BASIC ANALYSIS USING BEST DATA ESTIMATES  */
      |
      |
 114  |L=1;
      |
 115  |PUT EDIT('BEST DATA ESTIMATES')(PAGE,SKIP(5),A);
 116  |PUT EDIT('DATA')(SKIP(3),A);
 117  |GET DATA COPY;
 118  |HEADING = 'BASIC ANALYSIS';
 119  |CALL VALUES;
      |
      |
      |/* PARAMETRIC ANALYSES  */
      |
      |
      |
      |/* ANALYSIS OF VARIOUS DISCOUNT RATES */
 120  |L=3;
 121  |WORK(1) = DISCOUNT_RATE;
 122  |WORK(2) = ID;
 123  |HEADING = 'DISCOUNT/INTEREST RATE EFFECTS ANALYSIS';
 124  |PARAM = 'DISCOUNT_RATE';
 125  |DO D = .01 TO .13  BY .02;
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 126   |    DISCOUNT_RATE = D;                                             |
 127   |    PARAMVAL = DISCOUNT_RATE;                                      |
 128   |    ID = DISCOUNT_RATE + .12;                                      |
 129   |    CALL VALUES;                                                   |
 130   |END;                                                               |
 131   |DISCOUNT_RATE = WORK(1);                                           |
 132   |ID = WORK(2);                                                      |
       |                                                                   |
       |                                                                   |
       |                                                                   |
       |/* ANALYSIS OF VARIOUS PRICES FOR 100000 MILE TIRES  */            |
 133   |L= 3;                                                              |
 134   |WORK(1) = AV_100000_MILE_TIRE_PRICE;                               |
 135   |HEADING='ANALYSIS OF VARIOUS PRICES FOR 100000 MILE TIRES';        |
 136   |PARAM='AV_100000_MILE_TIRE_PRICE';                                 |
 137   |DO D= 150,125,115,110,105,88,37.02;                                |
 138   | AV_100000_MILE_TIRE_PRICE = D;                                    |
 139   | PARAMVAL=AV_100000_MILE_TIRE_PRICE;                               |
 140   | CALL VALUES;                                                      |
 141   |END;                                                               |
 142   |AV_100000_MILE_TIRE_PRICE = WORK(1);                               |
       |                                                                   |
       |                                                                   |
       |                                                                   |
       |/* ANALYSIS OF 100000 MILE TIRE PRODUCTION COSTS */                |
 143   |L = 5;                                                             |
 144   |WORK(1) = ONE_HUND_MI_TIRE_PROD_COST;                              |
 145   |HEADING = 'ANALYSIS OF 100000 MILE TIRE PRODUCTION COSTS';         |
 146   |PARAM = 'ONE_HUND_MI_TIRE_PROD_COST';                              |
 147   |DO D = 10,20;                                                      |
 148   | ONE_HUND_MI_TIRE_PROD_COST = ONE_HUND_MI_TIRE_PROD_COST + D;      |
 149   | PARAMVAL = ONE_HUND_MI_TIRE_PROD_COST;                            |
 150   | CALL VALUES;                                                      |
 151   |END;                                                               |
 152   |ONE_HUND_MI_TIRE_PROD_COST = WORK(1);                              |
       |                                                                   |
       |                                                                   |
       |                                                                   |
       |/* DEFINITION OF 100000 MILE TIRE PRODUCT VALUE BENEFITS SIMILAR TO |
       |RETREADINGS DEFINITION OF TOTAL PRODUCT VALUE, NOT INCREMENTAL */  |
 153   |L = 6;                                                             |
 154   |HEADING = 'ALTERNATIVE BENEFITS(8,1) DEFINITION';                  |
 155   |CALL VALUES;                                                       |
       |                                                                   |
       |                                                                   |
       |                                                                   |
       |/* INVESTIGATION OF VARIOUS ROAD REPAIR FREQUENCIES */             |
 156   |L = 7;                                                             |
 157   |HEADING = 'FIVE YEAR INTERVAL BETWEEN CONV. ROAD REPAIRS';         |
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 158  |CALL VALUES;
 159  |L = 8;
 160  |HEADING = 'TEN YEAR INTERVAL BETWEEN CONV. ROAD REPAIRS';
 161  |CALL VALUES;
      |
      |
      |
      |/* ANALYSIS OF ALTERNATIVE COSTS FOR ROAD REPAIRS */
 162  |L = 3;
 163  |WORK(1) = RC;
 164  |HEADING = 'ANALYSIS OF ALTERNATIVES FOR CONV. ROAD REPAIR COSTS';
 165  |PARAM = 'RC';
 166  |DO D = 8000,6366;
 167  | RC = D;
 168  | PARAMVAL = RC;
 169  | CALL VALUES;
 170  |END;
 171  |RC = WORK(1);
      |
      |
      |/* ANALYSIS OF VARIOUS RETREADED TIRE PRICES */
 172  |L = 9;
 173  |WORK(1)=AV_RETREAD_TIRE_PRICE;
 174  |HEADING = 'ANALYSIS OF RETREADED TIRE PRICES';
 175  |PARAM = 'RETREAD TIRE PRICE';
 176  |DO D = 27,37,47,57;
 177  | AV_RETREAD_TIRE_PRICE = D;
 178  | PARAMVAL = AV_RETREAD_TIRE_PRICE;
 179  | CALL VALUES;
 180  |END;
 181  |AV_RETREAD_TIRE_PRICE = WORK(1);
      |
      |
      |
      |/* ANALYSIS OF FOUR INDEPENDENT DATA CHANGES */
 182  |L = 3;
 183  |WORK(1) = PC;
 184  |WORK(2) = LAND_PRICE_PER_ACRE;
 185  |WORK(3) = COAL_PRICE_PER_TON;
 186  |WORK(4) = BELTED_BIAS_PROD_COST;
 187  |HEADING = 'FOUR INDEPENDENT DATA CHANGES';
 188  |PARAM = 'PRICE OF RECOVERED CARBON';
 189  | PC = .01;
 190  | LAND_PRICE_PER_ACRE = 1000;
 191  | BELTED_BIAS_PROD_COST = 18;
 192  | COAL_PRICE_PER_TON = 25;
 193  | PARAMVAL = PC;
 194  | CALL VALUES;
 195  |PC=WORK(1);
```

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 196   |LAND_PRICE_PER_ACRE = WORK(2);
 197   |COAL_PRICE_PER_TON = WORK(3);
 198   |BELTED_BIAS_PROD_COST = WORK(4);
       |
       |
       |
       |/* ANALYSIS OF VARIOUS SERVICE LIVES FOR TIRES */
 199   |L=6;
 200   |WORK(1) = TOTAL_MILEAGE_PER_TIRE(8);
 201   |WORK(2) = AV_100000_MILE_TIRE_PRICE;
 202   |WORK(3)=TOTAL_MILEAGE_PER_TIRE(6);
 203   |HEADING = 'ANALYSIS OF VARIOUS SERVICE LIVES FOR TIRES';
 204   |PARAM = 'DESIGN SERVICE LIFE';
 205   |DO D = 50000,75000,125000,150000,200000;
 206   |TOTAL_MILEAGE_PER_TIRE(8) = D;
 207   |AV_100000_MILE_TIRE_PRICE = AV_38000_MILE_TIRE_PRICE * D / TOTAL_MILEAG
       |E_PER_TIRE(1);
 208   |TOTAL_MILEAGE_PER_TIRE(6) =.25*D;
 209   |PARAMVAL = TOTAL_MILEAGE_PER_TIRE(8);
 210   |CALL VALUES;
 211   |END;
 212   |TOTAL_MILEAGE_PER_TIRE(8) = WORK(1);
 213   |TOTAL_MILEAGE_PER_TIRE(6)=WORK(3);
 214   |AV_100000_MILE_TIRE_PRICE=WORK(2);
       |
       |
       |
       |
       |/* ANALYSIS OF THE COST OF APPLICATION OF ASPHALT RUBBER  */
 215   |WORK(1) = RRC;
 216   |HEADING = 'ANALYSIS OF RRC';
 217   |PARAM = 'ROAD REPAIR COST';
 218   |DO D = .50,.75,1.00,1.50,2.00,2.32;
 219   |  RRC = D;
 220   |  PARAMVAL = RRC;
 221   |  CALL VALUES;
 222   |END;
 223   |RRC = WORK(1);
       |
       |
       |
       |/* ANALYSIS OF VARIOUS REFERENCE TIRE PRICES */
 224   |WORK(1)=AV_38000_MILE_TIRE_PRICE;
 225   |WORK(2)=TOTAL_MILEAGE_PER_TIRE(7);
 226   |TOTAL_MILEAGE_PER_TIRE(7)=36000;
 227   |HEADING='PRICE $50  MILEAGE 36000';
 228   |PARAM='PRICE/MILEAGE DECREASE      MILEAGE=. ';
 229   |PARAMVAL=AV_38000_MILE_TIRE_PRICE;
 230   |DO D = 55,50,45,40,37.02;
```

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 231  | AV_38000_MILE_TIRE_PRICE=0;
 232  |CALL VALUES;
 233  |END;
 234  |AV_38000_MILE_TIRE_PRICE=65.50;
 235  |TOTAL_MILEAGE_PER_TIRE(7)=40000;
      |
      |
      |
      |
 236  |VALUES: PROCEDURE;
      |/* A PROCEDURE WHICH COLLATES, CALCULATES, AND INTEGRATES NINE
      |   CATEGORIES OF COSTS AND FIVE CATEGORIES OF BENEFITS IN CONVENTIONAL
      |   AND SOCIAL COST BENEFIT ANALYSES FOR WORN PASSENGER CAR TIRE
      |   MANAGEMENT, THIS PROCEDURE, STATEMENTS 205 TO 380, PROCESSESES ALL
      |   OF THE CALCULATIONS DOCUMENTED IN THE DISSERTATION.  */
      |
      |
      |
      |
      |/*  INITIALIZATIONS   */
      |
      |
 237  |DO J=1 TO 5;
 238  |   BENEFITS(*,J)=0;
 239  |END;
 240  |DO I = 1 TO N;
 241  |  DO J = 1 TO 5,7 TO 9;
 242  |      COSTS(I,J) = 0;
 243  |  END;
 244  |FORW: END;
 245  |TAXHOLD=0; /* THIS IS TO AVOID NUMERICAL ERRORS IN C(6,9) LATER */
 246  |COSTS(7,6),COSTS(8,6)=0;
 247  |COSTS(2,6),COSTS(6,6),COSTS(8,6)=0;
      |
      |
      |
      |/* CALCULATIONS OF SERVICE LIFE AND SOLID WASTE GENERATION  CHAR. */
      |
 248  |DO I = 1 TO N;
 249  |  TIRE_YEARS_LIFE(I)=TOTAL_MILEAGE_PER_TIRE(I)/MILEAGE_USE_PER_YEAR;
 250  |END;
 251  |DO I= 1 TO N;
 252  |WASTE_PROPORTION(I)=TIRE_YEARS_LIFE(I)*(1/TIRE_YEARS_LIFE(I));
 253  |END;
 254  |WASTE_DECREASE_PT_PER_YEAR=0;
 255  |DO I = 1 TO N;
 256  |  WASTE_DECREASE_PT_PER_YEAR(I)=1 - WASTE_PROPORTION(I);
 257  |END;
      |
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     |
     |/* CALCULATION OF PRICES FOR RETREADS, NEW CONVENTIONAL, & 100000 MILE
     |TIRES. 100000 MILE TIRE CALCULATION INCLUDES DISCOUNTING. RETREAD PRICE
     |SHOULD DISCOUNT TOO BUT DOESNT  */
     |
     |
 258 |DO I=1 TO N;
 259 |TIRE_MILEAGE_PRICE_EQUIVALENT=(TIRE_YEARS_LIFE(I))*(AV_38000_MILE_TIRE_
     |PRICE/TIRE_YEARS_LIFE(1));
 260 |END;
 261 |WORK(7)=1 + 1/(1+DISCOUNT_RATE)**4 +1/(1+DISCOUNT_RATE)**8 +
     | 1/(1+DISCOUNT_RATE)**12 +1/(1+DISCOUNT_RATE)**16;
 262 |WORK(9)= 1 + 1/(1+ID)**4 + 1/(1+ID)**8 + 1/(1+ID)**12 + 1/(1+ID)**16;
 263 |WORK(8) = AV_33000_MILE_TIRE_PRICE * WORK(9);
 264 |TIRE_MILEAGE_PRICE_EQUIVALENT(8) = WORK(8)/(1 + 1/(1+ID)**TIRE_YEARS_LI
     |FE(8));
     |
     |
     |
     |/* CALCULATION OF TIRE PRODUCTION COSTS */
     |
     |
 265 |RADIAL_38S_PROD_COST =(BELTED_BIAS_PROD_COST * (1+COST_INDEX)) *(1.4+
     |SL * .12);
 266 |HM = (DT*DI) + (DQ-DD) + (DW*DS+DW*DI);
     |/* HM IS ADDITIONAL MATERIAL NEEDED FOR A 100000 MILE TIRE */
 267 |IF L ¬= 5 THEN
     |ONE_HUND_MI_TIRE_PROD_COST = RADIAL_38S_PROD_COST * (1 +
     |MATERIALS_PROPORTION * HM + SL * HL + SO * HO);
     |
     |
     |/*  PRINT INTERMEDIATE CALCULATION RESULTS  */
     |
     |
 268 |DO;
 269 |PUT EDIT('INTERMEDIATE, CALCULATED, DATA')(PAGE,SKIP(5),X(20),A);
 270 |PUT EDIT(HEADING)(SKIP,X(10),A);
 271 |IF L = 3 THEN
     |PUT EDIT(PARAM,'= ',PARAMVAL)(SKIP,X(15),A,A,F(15,3));
 272 |DO I = 1 TO N;
 273 |PUT EDIT('TYL(',I,') =',TIRE_YEARS_LIFE(I))(SKIP(1),A,F(1),A,F(6,2));
 274 |END;
 275 |DO I = 1 TO N;
 276 |PUT EDIT('WASTE PROPORTION (',I,') =',WASTE_PROPORTION(I))(SKIP(1),A,
     |          F(1),A,F(6,2));
 277 |END;
 278 |DO I = 1 TO N;
 279 |  PUT EDIT('WASTE DECREASE PER TIRE PER YEAR (',I,')=',WASTE_DECREASE_P
     |T_PER_YEAR(I))(SKIP,A,F(1),A,F(6,2));
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 280   |END;
 281   |DO I = 1 TO N;
 282   |PUT EDIT('TMPE(',I,') =',TIRE_MILEAGE_PRICE_EQUIVALENT(I))
       |          (SKIP(1),A,F(1),A,F(6,2));
 283   |END;
 284   |PUT EDIT('RADIAL_38S_PRCD_COST= ',RADIAL_38S_PRCD_COST)(SKIP,A,F(5,2));
 285   |PUT EDIT('100 MILE TIRE PRODUCTION COST=',ONE_HUND_MI_TIRE_PROD_COST)
       |             (SKIP(1),A,F(6,2));
 286   |PUT EDIT('AV_100000_MILE_TIRE_PRICE = ',AV_100000_MILE_TIRE_PRICE)
       |          (SKIP,A,F(6,2));
 287   |PUT EDIT('HM =  ',HM)(SKIP(1),A,F(6,2));
 288   |END;
       |
       |
       |/* TIRES COST/BENEFIT CALCULATIONS   */
       |
       |
 289   |CONTIN:
       |
       |
       |
       |/* CALCULATION OF COLLECTION COSTS */
       |COSTS(*,1) = .01;
 290   |COSTS(6,1) = 1;
 291   |DO I = 1 TO N;
 292   | IF (I = 4 & L = 2) THEN GO TO CONTI;
 293   |  COSTS(I,2)=(AV_DEALERS_MONTHLY_RENTAL*WORN_TIRE_STORAGE_PROPORTION) /
       |200;
 294   |  COSTS(I,3)=GRADING_COSTS+BATCH_COLLECTION_COSTS;
 295   |  COSTS(I,4)=HAUL_COSTS+HANDLING_COSTS;
 296   |  COSTS(I,5)=CHOPPING_COSTS;
 297   |CONTI: END;
 298   |  COSTS(5,5)=GRINDING_COSTS;
 299   |  DO I= 1 TO 5;
 300   |  COSTS(6,I)=WASTE_PROPORTION(6)* COSTS(6,I);
 301   |  COSTS(7,I)=WASTE_PROPORTION(7)* COSTS(7,I);
 302   |  COSTS(8,I)=WASTE_PROPORTION(8)* COSTS(8,I);
 303   |  END;
       |
       |
       |/* PROCESSING AND WASTE HANDLING COST CALCULATIONS */
       |
 304   |  ENVR_QUALITY_COSTS=COSTS(4,1)+COSTS(4,2)+COSTS(4,3)+COSTS(4,4) +
       |                     COSTS(4,5)+COSTS(4,6)+COSTS(4,7);
 305   |PUT EDIT('ENVIRONMENTAL QUALITY COSTS = ',ENVR_QUALITY_COSTS)(SKIP(1),A
       |,F(6,2));
       |
       |
 306   |NB = TW * PC * GA * AB * NT;
```

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 307   |CRYOGENICS_COST = CY * POUNDS_PER_WASTE_TIRE;
 308   |ROAD_REPAIR_COST = RRC * AB / NB;
 309   |COSTS(2,6) = ROAD_REPAIR_COST;
 310   |PUT EDIT('CRYOGENICS COST = ',CRYOGENICS_COST)(SKIP(1),A,F(6,2));
 311   |PUT EDIT('ROAD_REPAIR COST = ',ROAD_REPAIR_COST)(SKIP(1),A,F(6,2));
 312   |IF L = 6 THEN
       |  COSTS(6,6)= RET_PROC_COST+WASTE_PROPORTION(6)*ENVR_QUALITY_COSTS;
 313   |ELSE
       |COSTS(6,6)=RET_PROC_COST - RADIAL_38S_PROD_COST + WASTE_PROPORTION(6) *
       |ENVR_QUALITY_COSTS;
 314   |IF L = 6 THEN
       |COSTS(8,6)= ONE_HUND_MI_TIRE_PROD_COST * TIRE_YEARS_LIFE(1)/TIRE_YEARS_
       |LIFE(8);
 315   |ELSE
       |COSTS(8,6)= (ONE_HUND_MI_TIRE_PROD_COST * (1+1/(1+ID)**10) -
       |(RADIAL_38S_PROD_COST * (1+ 1/(1+ID)**4 + 1/(1+ID)**8 + 1/(1+ID)**12
       | + 1/(1+ID)**16)))* (TIRE_YEARS_LIFE(1)/(2*TIRE_YEARS_LIFE(8)))
       |                             *(1+ID)**TIRE_YEARS_LIFE(1);
 316   |COSTS(8,6)= COSTS(8,6) + WASTE_PROPORTION(8)*(COSTS(4,6)+COSTS(4,7));
       |
       |
       |/* CALCULATIONS OF ADMIN AND MARKETING COST EFFECTS */
       |
 317   |DO I=1 TO 4;
 318   |  COSTS(I,7)=ADMIN_MKTG_COST_FACTOR_LOW * COSTS(I,6);
 319   |END;
 320   |COSTS(5,7)=ADMIN_MKTG_COST_FACTOR_HIGH * COSTS(5,6);
 321   |COSTS(6,7)=ADMIN_MKTG_COST_FACTOR_RETREADS * COSTS(6,6);
 322   |IF COSTS(6,6) <0 THEN COSTS(6,7) = 0;
 323   |COSTS(8,7)=ADMIN_MKT_COST_FACTOR_100000_MI * COSTS(8,6);
 324   |IF COSTS(8,6)<0 | L=6 THEN COSTS(8,7) = COSTS(8,7)*(-1);
       |
       |
       |
       |/* CALCULATIONS OF PRODUCT VALUES BENEFITS */
       |
 325   |BENEFITS(1,1) = (COAL_PRICE_PER_TON * UW * POUNDS_PER_WASTE_TIRE * RB)/
       |(2000 * UL);
 326   |BENEFITS(2,1)=RAMFLEX_PRICE + PA * DX - CRYOGENICS_COST;
 327   |BENEFITS(3,1) = 0;
 328   |BENEFITS(4,1)=(LAND_PRICE_PER_ACRE)/(6*43560);
 329   |RETREAD:
       |BENEFITS(5,1) = DC * PC + DC * PO + DX * PA;
 330   |IF L = 6 THEN
       |BENEFITS(6,1)=AV_RETREAD_TIRE_PRICE ;
 331   |ELSE
       |BENEFITS(6,1) = AV_RETREAD_TIRE_PRICE - .8 * AV_38000_MILE_TIRE_PRICE +
       |BENEFITS(2,1)/(1+ID)**TIRE_YEARS_LIFE(1)- BENEFITS(2,1);
 332   |BENEFITS(7,1) = 0;
```

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 333  |IF L = 6 THEN
      |BENEFITS(8,1)= AV_100000_MILE_TIRE_PRICE*(1+1/(1+ID)**TIRE_YEARS_LIFE(8
      |))*TIRE_YEARS_LIFE(1)/(2*TIRE_YEARS_LIFE(8)) ;
 334  |ELSE
      |BENEFITS(8,1)=(AV_100000_MILE_TIRE_PRICE*(1+1/(1+ID)**TIRE_YEARS_LIFE(8
      |))+ BENEFITS(2,1)*(1+HM)*(1/(1+ID)**TIRE_YEARS_LIFE(8)) - AV_38000_MILE
      |_TIRE_PRICE* WORK(9) - BENEFITS(2,1)*(WORK(9)-1)) * TIRE_YEARS_LIFE(1)/
      |(2*TIRE_YEARS_LIFE(8))
      |* (1 + (1/(TIRE_YEARS_LIFE(1)/2)*(1+ID)**TIRE_YEARS_LIFE(1)-1));
 335  |PUT EDIT('BENEFITS(6,1)   = ',BENEFITS(6,1))(SKIP(1),A,F(6,2));
 336  |PUT EDIT('BENEFITS(8,1)   = ',BENEFITS(8,1))(SKIP(1),A,F(6,2));
      |
      |
      |
      |/* ADDITION OF DECREASED WASTES BENEFITS TO PRODUCT VALUE BENEFITS */
      |
 337  |DO I = 1 TO 5;
 338  |  BENEFITS(I,1) = BENEFITS(I,1) + COSTS(4,6) + COSTS(4,7);
 339  |END;
 340  |DO I = 6 TO 8;
 341  |  BENEFITS(I,1) = BENEFITS(I,1) + WASTE_DECREASE_PT_PER_YEAR(I) *
      |ENVR_QUALITY_COSTS;
 342  |END;
      |
      |
      |
      |/* CALCULATIONS OF EMPLOYMENT EFFECTS */
      |
 343  |DO I = 1 TO 5;
 344  |  COSTS(I,8) = -OL * BENEFITS(I,1);
 345  |END;
 346  |IF L = 7 THEN
      |COSTS(2,8)=COSTS(2,8) + OL * RAMFLEX_PRICE * (1/(1+DISCOUNT_RATE)**5);
 347  |IF L = 8 THEN COSTS(2,8) = COSTS(2,8);
 348  |ELSE
      |COSTS(2,8)=COSTS(2,8) + OL * RAMFLEX_PRICE * (1/(1+DISCOUNT_RATE)**3.33
      |+1/(1+DISCOUNT_RATE)**6.66);
 349  |COSTS(6,8) = SL *  8 * RADIAL_38S_PROD_COST - SR * RET_PROC_COST;
 350  |COSTS(8,8) = (SL + HL) * ONE_HUND_MI_TIRE_PROD_COST - 2.5 * SL *
      |RADIAL_38S_PROD_COST * (TIRE_YEARS_LIFE(1)/TIRE_YEARS_LIFE(8));
      |
      |
      |
      |/* CALCULATION OF TAX COSTS AND BENEFITS FOR TIRE RECOVERY */
      |
 351  |DO I = 1 TO 5;
 352  | COSTS(I,9)=(BENEFITS(I,1)-COSTS(I,1)-COSTS(I,2)-COSTS(I,3)-COSTS(I,4)-
      | COSTS(I,5)-COSTS(I,6)-COSTS(I,7));
 353  | IF COSTS(I,9) >  0 THEN COSTS(I,9)=COSTS(I,9)* CORP_PROFIT_TAX_RATE;
```

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 354   | ELSE COSTS(I,9)=0;                                                      |
 355   |END;                                                                     |
 356   |DO I = 1 TO 5;                                                           |
 357   |  BENEFITS(I,3) = COSTS(I,9);                                            |
 358   |END;                                                                     |
       |                                                                         |
       |                                                                         |
       |                                                                         |
       |/* CALCULATION OF TAX EFFECTS FOR RETREADING & 100000 MILE TIRES */      |
       |                                                                         |
 359   |IF L = 6 THEN                                                            |
       |DO;                                                                      |
 360   |BENEFITS(6,3)=CORP_PROFIT_TAX_RATE *((PROFIT_RATE(7) * AV_RETREAD_TIRE_|
       |PRICE - ADMIN_MKTG_COST_FACTOR_RETREADS * RET_PROC_COST)-(PROFIT_RATE(8|
       |) * .8 * AV_38000_MILE_TIRE_PRICE - EXL));                               |
       |/* BENEFITS(7,3) EQUAL ZERO */                                           |
 361   |BENEFITS(8,3)=CORP_PROFIT_TAX_RATE *((PROFIT_RATE(8) * AV_100000_MILE_T|
       |IRE_PRICE - EXAV) *(TIRE_YEARS_LIFE(1)/TIRE_YEARS_LIFE(8)) - (PROFIT_RA|
       |TE(7) * AV_38000_MILE_TIRE_PRICE - EXAV));                               |
 362   |END;                                                                     |
 363   |ELSE                                                                     |
       |DO;                                                                      |
 364   |BENEFITS(6,3)=CORP_PROFIT_TAX_RATE * (PROFIT_RATE(7) * AV_RETREAD_TIRE_|
       |PRICE - ADMIN_MKTG_COST_FACTOR_RETREADS * RET_PROC_COST);               |
 365   |BENEFITS(8,3)=CORP_PROFIT_TAX_RATE * (PROFIT_RATE(8) * AV_100000_MILE_T|
       |IRE_PRICE - EXAV) *(TIRE_YEARS_LIFE(1)/TIRE_YEARS_LIFE(8)) ;            |
 366   |END;                                                                     |
 367   |DO I = 6 TO 8;                                                           |
 368   |IF BENEFITS(I,3) > 0 THEN COSTS(I,9) = BENEFITS(I,3);                    |
 369   |ELSE COSTS(I,9) = 0;                                                     |
 370   |END;                                                                     |
       |                                                                         |
       |                                                                         |
       |/* CALCULATION OF VALUE FROM THE VIEWPOINT OF THE TIRE INDUSTRY */       |
       |                                                                         |
 371   |DO I= 1 TO 8;                                                            |
 372   |INTERNAL_COSTS(I)=COSTS(I,1)+COSTS(I,2)+COSTS(I,3)+COSTS(I,4)+COSTS(I,5|
       |)+COSTS(I,6)+COSTS(I,7)               +COSTS(I,9);                       |
 373   |END;                                                                     |
 374   |DO I=1 TO 8;                                                             |
 375   |  INTERNAL_VALUE(I) = BENEFITS(I,1) - INTERNAL_COSTS(I);                 |
 376   |END;                                                                     |
 377   |INTERNAL_VALUE(2)=INTERNAL_VALUE(2) + ROAD_REPAIR_COST * (1 + ADMIN_MKT|
       |G_COST_FACTOR_LOW);                                                      |
 378   |INTERNAL_VALUE(3)=0;                                                     |
 379   |INTERNAL_VALUE(7)=0;                                                     |
       |                                                                         |
       |                                                                         |
       |                                                                         |
```

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```
STMT

      |/* CALCULATION OF TIRE RUBBER ASPHALT COSTS AVOIDED AND INTEREST
      |BENEFITS  */
      |
      |
      |/* NB WAS CALCULATED ABOVE AT ABOUT STATEMENT 278 */
 380  |IF L = 7 THEN
      |DO;
 381  |SIP =((RC-CTRA)*((1+DISCOUNT_RATE)**10-1))/(1+DISCOUNT_RATE)**10 +
      |(RC*((1+DISCOUNT_RATE)**5-1))/(1+DISCOUNT_RATE)**10;
 382  |CSP= (RC-CTRA) + RC/(1+DISCOUNT_RATE)**5;
 383  |END;
 384  |IF L = 8 THEN
      |DO;
 385  |SIP=((RC-CTRA)*((1+DISCOUNT_RATE)**10-1))/(1+DISCOUNT_RATE)**10;
 386  |CSP=(RC-CTRA);
 387  |END;
 388  |ELSE DO;
 389  |SIP=((RC-CTRA)*((1+DISCOUNT_RATE)**10-1))/(1+DISCOUNT_RATE)**10 +
      |(RC*(((1+DISCOUNT_RATE)**6.66-1))/(1+DISCOUNT_RATE)**10 + (RC*(((1+
      |DISCOUNT_RATE)**3.33-1))/(1+DISCOUNT_RATE)**10;
 390  |CSP = (RC-CTRA) + RC/(1 + DISCOUNT_RATE)**3.33 + RC/(1 + DISCOUNT_RATE)
      |**6.66;
 391  |     END;
 392  |PUT EDIT('NB, SIP, CSP  = ',NB,SIP,CSP)(SKIP(1),A,F(6,2),X(3),F(6,2),X(
      |3),F(6,2));
 393  |BENEFITS(2,2) = ((CSP + SIP)/NB)*(TIRE_YEARS_LIFE(1)/TIRE_YEARS_LIFE(8)
      |) + PA * DX;
 394  |BENEFITS(6,2)=AV_38000_MILE_TIRE_PRICE -(AV_RETREAD_TIRE_PRICE *
      |(TOTAL_MILEAGE_PER_TIRE(1)/(TOTAL_MILEAGE_PER_TIRE(6)-TOTAL_MILEAGE_PER
      |_TIRE(1)))) ;
 395  |BENEFITS(8,2)=AV_38000_MILE_TIRE_PRICE -(AV_100000_MILE_TIRE_PRICE *
      | (TOTAL_MILEAGE_PER_TIRE(1)/TOTAL_MILEAGE_PER_TIRE(8)));
      |
      |
      |
      |/* CALCULATION OF PHYSICAL ENVIRONMENT BENEFITS */
      |
 396  |DO I = 1 TO 8;
 397  | BENEFITS(I,4)=ENVR_QUALITY_COSTS;
 398  |END;
 399  | BENEFITS(6,4)= BENEFITS(6,4)*WASTE_DECREASE_PT_PER_YEAR(6);
 400  |BENEFITS(8,4)=  BENEFITS(4,4)*WORK(7) - BENEFITS(4,4)*(1+HM)*(1/(1+DISC
      |OUNT_RATE)**(TIRE_YEARS_LIFE(8)-TIRE_YEARS_LIFE(1)))+1/(1+DISCOUNT_RATE
      |)**(2*TIRE_YEARS_LIFE(8)-TIRE_YEARS_LIFE(1));
 401  |BENEFITS(8,4)=BENEFITS(8,4)* TIRE_YEARS_LIFE(1)/(2*TIRE_YEARS_LIFE(8));
      |
      |
      |
      |/* CALCULATION OF CONSERVATION BENEFITS */
```

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STMT

      |
 402  |BENEFITS(1,5) = BENEFITS(1,1);
 403  |BENEFITS(2,5) = (CE - CS - CF) / NS;
 404  |BENEFITS(5,5) = BENEFITS(5,1);
 405  |BENEFITS(6,5)= RADIAL_385_PROD_COST * (MATERIALS_PROPORTION+.3*SO) *
      |WASTE_DECREASE_PT_PER_YEAR(6);
 406  |BENEFITS(8,5)= (RADIAL_385_PROD_COST * (MATERIALS_PROPORTION+.3*SO)*WOR
      |K(7) - ONE_HUND_MI_TIRE_PROD_COST*(MATERIALS_PROPORTION+.3*SO)*(1+1/(1+
      |DISCOUNT_RATE)**TIRE_YEARS_LIFE(8))) * TIRE_YEARS_LIFE(1)/(2*TIRE_YEARS
      |_LIFE(8));
      |
 407  |COSTS(3,*)=0;
 408  |COSTS(7,*)=0;
 409  |BENEFITS(3,*)=0;
 410  |BENEFITS(7,*)=0;
 411  |DO I=1 TO 8;
 412  |SOCIAL_VALUES(I) = SUM(BENEFITS(I,*))-COSTS(I,1) -COSTS(I,2)-COSTS(I,3)
      |-COSTS(I,4)-COSTS(I,5)-COSTS(I,6)-COSTS(I,7)-COSTS(I,8)-COSTS(I,9);
 413  |END;
 414  |DO I=1 TO 8;
 415  |C(I)=SOCIAL_VALUES(I);
 416  |END;
      |
      |
      |
      |/*  END: COST/BENEFIT CALCULATIONS    */
      |/*  PRINT OUTPUT NEXT    */
      |
 417  |CALL CBPRINT;
 418  |PUT EDIT('SOCIAL VALUE COEFFICIENTS')(SKIP(2),X(20),A);
 419  |PUT EDIT('ASPHALT ADDITIVE',C(2))(SKIP,X(22),A,X(11),F(7,2));
 420  |PUT EDIT('LAND RECLAMATION',C(4))(SKIP,X(22),A,X(11),F(7,2));
 421  |PUT EDIT('INCINERATION',C(1))(SKIP,X(22),A,X(15),F(7,2));
 422  |PUT EDIT('PYROLYSIS                  ',C(5))(SKIP,X(22),A,X(3),F(7,2));
 423  |PUT EDIT('RETREADING',C(6))(SKIP,X(22),A,X(17),F(7,2));
 424  |PUT EDIT('100000 MILE TIRES',C(8))(SKIP,X(22),A,X(10),F(7,2));
 425  |PUT EDIT('TIRE INDUSTRY VALUE COEFFICIENTS')(SKIP(2),X(20),A);
 426  |PUT EDIT('ASPHALT ADDITIVE',INTERNAL_VALUE(2))(SKIP,X(22),A,X(11),F(7,2
      |));
 427  |PUT EDIT('LAND RECLAMATION',INTERNAL_VALUE(4))(SKIP,X(22),A,X(11),F(7,2
      |));
 428  |PUT EDIT('INCINERATION',INTERNAL_VALUE(1))(SKIP,X(22),A,X(15),F(7,2));
 429  |PUT EDIT('PYROLYSIS                  ',INTERNAL_VALUE(5))(SKIP,X(22),A,X(3
      |),F(7,2));
 430  |PUT EDIT('RETREADING',INTERNAL_VALUE(6))(SKIP,X(22),A,X(17),F(7,2));
 431  |PUT EDIT('100000 MILE TIRES',INTERNAL_VALUE(8))(SKIP,X(22),A,X(10),F(7,
      |2));
 432  |RETURN; END;
      |
```

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```
OPTIMIZING COMPILER

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      |                                                                   |
      |                                                                   |
      |                                                                   |
 434  |CBPRINT: PROCEDURE;                                                |
 435  |PUT EDIT(HEADING)(PAGE,SKIP(11),X(20),A);                          |
 436  |IF (L=2|L=3|L=4|L=5|L=9|L=6) THEN                                  |
      |PUT EDIT(PARAM,'= ',PARAMVAL)(SKIP,X(20),A,A,F(10,3));             |
 437  |PUT EDIT('COSTS AND BENEFITS USED IN VALUE DEFINITIONS')(SKIP,X(20),A);|
 438  |PUT SKIP;                                                          |
 439  |PUT EDIT(('COSTS(',I,')' DO I=1 TO 9))(SKIP,X(22),9 (A,F(1),A,X(2)));  |
 440  |PUT EDIT(COSTS)(SKIP,X(20),8 (9 (F(8,2),X(2)),SKIP,X(20)));        |
 441  |PUT SKIP;                                                          |
 442  |PUT EDIT(('BENEFITS(',I,')' DO I=1 TO 5))(SKIP,X(24),5 (A,F(1),A,X(2)))|
      |;                                                                  |
 443  |PUT EDIT(BENEFITS)(SKIP,X(20),8 (5 (F(11,2),X(2)),SKIP,X(20)));    |
 444  |RETURN; END;                                                       |
      |                                                                   |
      |                                                                   |
      |                                                                   |
 446  |END DISSERT;                                                       |
 447  |END TIREC;                                                         |
```

APPENDIX C

DATA INPUTS

The data on the following pages were printed by Tirec II and represent our best estimates of the data relevant to the Tirec II cost/benefit analysis. The sources of the data, when relevant, are listed in the Appendices; otherwise the data represent common sense choices of numbers such as the value of .08 used for the discount rate.

Some of the data was taken from the author's doctoral dissertation, "The Management of Waste Passenger Car Tires", completed at the Wharton School, University of Pennsylvania, in 1974. Some data used in this 1974 Tirec I work was left in Tirec II, but was not used. This included:

```
CAPITAL_PTPD_CONVERSION_COSTS=2750,
RET_OPP_COST_TO_MANUFACTURERS=21.00,
PLANT_SIZE_TPD=10000,
```

The variable names of TirecI were written out so as to be understandable without reference to a list of definitions. For example: "DISCOUNT_RATE" is the name used in the Program to represent the discount rate. These data are listed on the following page, the first page of data. The second data page includes new variables defined for the Tirec II research. These data were given identifiers (names) which are the same as is given in the glossary of definitions at the end of this report except that the subscript letters could not be printed by the computer/ The subscripts are printed as regular letters in their expected positions, however. For example:

S_L = SL in Tirec II

P_c = PC in Tirec II

Thirty-seven new variables were added to the Tirec program as part of the Tirec II research.

```
DATA
 AV_100000_MILE_TIRE_PRICE = 107,
 CORP_PROFIT_TAX_RATE=.22,
 DISCOUNT_RATE=.08,
 DESTRUCTIVE_DIST_PRODUCTS_PRICE=.46,
 AV_RETREAD_TIRE_PRICE=16.22,
 COAL_PRICE_PER_TON=45,
 LAND_PRICE_PER_ACRE=10000,
 BELTED_BIAS_PROD_COST=15.00,
 RET_PROC_COST=8.92,
 AV_BELTED_BIAS_TIRE_PRICE=37.02,
 CAPITAL_PTPD_CONVERSION_COSTS=2750,
 RET_OPP_COST_TO_MANUFACTURERS=21.00,
 PLANT_SIZE_TPD=10000,
 ADMIN_MKTG_COST_FACTOR_38000_MI=-.35,
 COSTS(1,6)=.52,
 COSTS(3,6)=.17,
 COSTS(4,6)=.05,
 COSTS(5,6)=.25,
 AV_DEALERS_MONTHLY_RENTAL=1000,
 WORN_TIRE_STORAGE_PROPORTION=.01,
 GRADING_COSTS=.13,BATCH_COLLECTION_COSTS=.57,
 HAUL_COSTS=.11,HANDLING_COSTS=.02,
 CHOPPING_COSTS=.25,
 GRINDING_COSTS=.43,
 AV_38000_MILE_TIRE_PRICE=65.50,
 MILEAGE_USE_PER_YEAR=10000,
 TOTAL_MILEAGE_PER_TIRE(1)=40000,
 TOTAL_MILEAGE_PER_TIRE(2)=40000,
 TOTAL_MILEAGE_PER_TIRE(3)=40000,
 TOTAL_MILEAGE_PER_TIRE(4)=40000,
 TOTAL_MILEAGE_PER_TIRE(5)=40000,
 TOTAL_MILEAGE_PER_TIRE(6)=80000,
 TOTAL_MILEAGE_PER_TIRE(7)=40000,
 TOTAL_MILEAGE_PER_TIRE(8)=100000,
 COST_INDEX = 0.,
 MATERIALS_PROPORTION= .475,
 ADMIN_MKTG_COST_FACTOR_LOW=.15,
 ADMIN_MKTG_COST_FACTOR_HIGH=.25,
 ADMIN_MKTG_COST_FACTOR_RETREADS=.20,
 ADMIN_MKT_COST_FACTOR_100000_MI=-.35,
 POUNDS_PER_WASTE_TIRE=20,
 PROFIT_RATE(1)=.36,
 PROFIT_RATE(7)=.50,
 PROFIT_RATE(8)=.50,
 TIRE_CARCASS_VALUE_PROPORTION=.80;
 RAMFLEX_PRICE=2,
```

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```
  SL = .275,
  HL = .250,
  HC = .40,
  CT = .15,
  DI = .35,
  DQ = .25,
  DD = .11,
  DW = .35,
  DS = .40,
  ID = .20,
  OL = .30,
  EXL = 19.62,
  EXAV = 40.03,
  UW = 15000,
  RB = .70,
  UL = 10000,
  TW = .25,
  PD = 7.5,
  GA = .5,
  NT = .07,
  NS = .07,
  AB = 3733,
 RC=11013,
 CTRA=8661,
 DC = 7,
 DO=.034,
 DX=.002,
 PC=.08,
 PO=7.50,
 PA = 45,
 SR = .23,
 SO = .250,
 CE = 1.91,
 CF = .65,
 CS = .91,
 CY = .05,
RRC = .75,
```

APPENDIX D

ROAD REPAIRS: TIRE ASPHALT RUBBER MIX (B_{11}) BENEFITS

The United States has entered an era of road maintenance and repairs; the major road construction work of the past decades has, for the most part, been completed. As time passes, these many roads built in the construction era will develop cracks, potholes, unevenness, and other failures.

> To extend the useful life of deteriorating roadways, generally accepted restoration typically involves the application of a thin asphaltic overlay...over the cracked and otherwise deformed pavement. Historically, however, the application of these thin overlays (generally of 4 inches or less) results in a new complex problem known as "Reflective Cracking"--defined as the migration of a subsurface cracking pattern into and subsequently through the overlay structure...Once the overlay is fractured, general erosion occurs which severely affects performance and requires further and costly maintenance (1).

The use of waste tire rubber in road repairing appears to have significant benefits in avoiding the costs, inconveniences, and road hazards involved in the repair of reflective cracks over and over again. In a study of various methods of road repairs, Arizona found that asphalt rubber repairs reflected only four percent of the underlying cracks in three years while control sections reflected seventeen percent of the cracks (2). The Arizona experiences indicate that roads repaired with tire asphalt rubber stay repaired for quite a while:

> "the surface is in excellent condition and shows only minor crack reflection after eight years of service" (3);

> "After six years of service, this Project has required no maintenance and shows only a few minor reflective cracks" (4).

The asphalt rubber process includes along with semi-conventional repairs, the placement of a 1/4 inch overlay consisting of 25 percent worn tire rubber and 75 percent asphalt. The engineering details of the process are described in the literature (5-6).

The Arizona Projects might have been successful due to the favorable climate of the Phoenix area where they were carried out. Accordingly, in August of 1973 a tire asphalt rubber road repair project was carried out at a severe winter weather location-- Flagstaff, Arizona. Flagstaff is at an elevation of 7200 feet with temperatures as low as -40 degrees farenheit (-5 degrees Celsius) and frost depths to three feet. The Project was reported, in 1976, to have "performed excellently with zero maintenance to date". It appears then, that the tire asphalt rubber road repair process will be valuable in a range of climates.

The highly favorable experiences of Arizona, however, have not yet been duplicated in a significant number of other states. Some tire asphalt rubber road repairs have been made in California and in South Dakota. California has indicated that tire asphalt rubber seems to work as intended. South Dakota has had poor results with the process (7). The poor South Dakota results may be due to the use of alternative quantities and types of rubbers used in repairs and/or due to different methods of application. A four year U. S. Environmental Protection Agency Project to document experience with the tire asphalt rubber repairs is in process and will be completed in 1981.

The Arizona and California experiences provide reasonable documentation with which to estimate the benefits of the tire asphalt rubber road repair process.

TIRE ASPHALT RUBBER REPAIRS

The benefits of the tire asphalt rubber repairs might be represented as the road repair costs avoided by use of the Process.

> Phoenix "streets require a new (conventional) seal coat every three to five years. The asphalt rubber (tire rubber asphalt) seals have exceeded seven years to date and it appears that they will last at least ten years" (8).

According to these estimates, in ten years we might need one tire asphalt repair or two or three conventional repairs.

The city of Phoenix, in 1972, reported the costs per city block, of conventional repairs, to be $1900. Comparable tire asphalt rubber repairs were reported to cost $2400. Arizona, in 1976, reported: (1) costs of $2.95 per square yard for a (conventional) three inch asphalt concrete overlay with a one half inch asphalt concrete finishing coat; and (2) costs of $2.32 per square yard for 1 1/4 inches of asphalt concrete followed by about 1/4 inch of the tire asphalt rubber chip coating and one half inch asphalt concrete finishing coat. These costs include "the total of all ingredients and operations and are estimations based on...a size job...generally more than 40,000 square yards". The cost of the tire asphalt rubber chip seal alone, accounts for about $.75 of the $2.32 on the average. California reported, in 1976, average costs of $1.91 per square yard for one to one and one half inches of asphalt overlay.

We multiplied 1976 cost figures times the 3733 square yards (3121.26 square meters) of the Phoenix block mentioned earlier in order to obtain 1976 "costs per block" useful in estimating the benefits of the tire asphalt rubber process. According to Arizona estimates, a "conventional" repair of the Phoenix block would cost $11,013 and would last as little as three years; a tire asphalt rubber interlayer repair would cost $8661, and would, we estimate based upon the Phoenix experience, last ten years. According to the

California information, conventional repairs to a block would cost $7130 and would last as long as seven years. We regarded the $8661 asphalt rubber cost as representative for California repairs.

ARIZONA ROAD REPAIR BENEFIT CALCULATION

Demolition and reconstruction of a city block, in 1977, might cost in the neighborhood of $86,000; sometimes reconstruction is necessary. Relatively thin repair overlays are suitable temporary substitutes for reconstruction as long as the coats do not raise the road so high as to cover curbs, storm drains, etc. One two inch thick tire asphalt rubber overlay, according to Arizona experience, can last ten years. Three 3 1/2 inch thick conventional overlays, a total of 10 1/2 inches thickness might be required in ten years as an alternative. Assuming that after 10 1/2 inches of road thickness build-up occurs the road must be reconstructed, we can say that five tire asphalt rubber road repairs may be used in place of both nine conventional 3 1/2 inch seals and two major road constructions (Table D-1). In addition to the costs avoided, we might say that the highway repair agency could invest these funds not spent to earn money during this period.

We took the present value of the repair costs avoided in ten years (the 10th to 20th years in Table D-1as if year 10 were the present time) plus the present value of the interest earnable in ten years on the savings from costs avoided, as one estimate of the total incremental benefits, in ten years, of tire asphalt rubber repairs to one city block. This did not include the possible substantial savings in major reconstruction beginning in year 20. We multiplied this by 4/10 to convert this to an average rate per four years.

We divided this result by the number of worn tires used in tire asphalt rubber reapirs to a city block. The result was an estimate of the benefits of the tire asphalt rubber process per waste tire utilized and per four years. We added to this the value of steel recovered from the waste tire in processing.

The present value of the repair costs avoided (cost savings) in ten years was represented as:

$$C_{sp} = (R_c - C_{tra}) + \frac{R_c}{(1+i)^{3.33}} + \frac{R_c}{(1+i)^{6.66}}$$

Where: R_c = conventional repair costs to one city block

C_{tra} = tire asphalt rubber repair costs to one city block

At a discount rate of ten per cent, and 1977 costs- R_c = \$11,013 and C_{tra} = \$8,661 -the benefits are:

$$(\$11{,}013 - \$8{,}661) + \frac{\$11{,}013}{(1.1)^{3.33}} + \frac{\$11{,}013}{(1.1)^{6.66}} = \$17{,}060$$

TABLE D-1. ROAD REPAIR AND RECONSTRUCTION MODEL COSTS

Beginning of year	Conventional repairs costs 3½ inch	Tire asphalt rubber repairs costs 1 3/4"	Cost savings
0.00	$86,000 first cycle	$86,000	-
3.33	-	-	-
6.67	-	-	-
10.00	$11,013	$ 8,661	$ 2,352
13.33	$11,013	-	$11,013
16.67	$11,013	-	$11,013
20.00	$86,000	$ 8,661	$77,339
23.33	-	-	-
26.67	-	-	-
30.00	$11,013	$ 8,661	$ 2,352
33.33	$11,013	-	$11,013
36.67	$11,013	-	$11,013
40.00	$86,000	$ 8,661	$77,339
43.33	-	-	-
46.67	-	-	-
50.00	$11,013	$ 8,661	$ 2,352
53.33	$11,013	-	$11,013
56.67	$11,013	-	$11,013
60.00	$86,000 second cycle	$86,000	-

Note: This assumes: (1) that original and reconstruction work lasts ten years and, (2) that a second asphalt rubber repair (and the third and fourth and fifth) would last ten years as does the first. This is not certain.

The present value of the interest earnable on the funds made available by avoiding these costs was represented as:

$$S_{ip} = \frac{(R_c - C_{tra})\ (1+I_g)^{10}-1}{(1+I_g)^{10}} + \frac{R_c(1+I_g)^{6.66}-1}{(1+I_g)^{10}} + \frac{R_c(1+I_g)^{3.33}-1}{(1+I_g)^{10}}$$

$$S_{ip} = \frac{(\$11{,}013-\$8{,}661)(1.1)^{10}-1}{(1.1)^{10}} + \frac{\$11{,}013(1.1)^{6.66}-1}{(1.1)^{10}} + \frac{\$11{,}013(1.1)^{3.33}-1}{(1.1)^{10}}$$

$$S_{ip} = \$5{,}739.20$$

The combined sum of the costs savings and interest benefits is \$22,799.63; the benefits each four years, including the revenues from recvoered steel, per solid waste tire are:

$$\text{Benefits} = \frac{\$22{,}799.63}{N_b}\left(\frac{4}{10}\right) + \$.07 = \$37.44$$

Where N_b = the number of solid waste passenger car tires used in tire asphalt rubber repairs to a city block

$$N_b = W_p P G A_b N$$

$$N_b = \left(\frac{\text{lbs. tire rubber}}{\text{gallon}}\right)\left(\frac{\text{gallons}}{\text{1 Sq Yd}}\right)\left(\frac{\text{Sq. Yards}}{\text{1 city block}}\right)\left(\frac{\text{No. of worn tires}}{\text{lb. tire asph. rb.}}\right)$$

$$= \frac{\text{worn tires}}{\text{1 city block}}$$

And

W_p = the proportion, by weight, of tire asphalt rubber which is worn tire rubber

P = the weight, in pounds per gallon, of tire asphalt rubber

G = the application rate, in gallons per square yard, for asphalt rubber

A_b = the area, in square yards, of a city block (Phoenix, Ariz. 3733 square yards)

N = the proportion of a tire that it takes to recover 1 pound of tire asphalt rubber

An example calculation follows:

$$N_b = (.25)\left(\frac{\text{7.5 lbs.}}{\text{1 gallon}}\right)\left(\frac{\text{.5 gallons}}{\text{1 sq. yd.}}\right)\left(\frac{\text{3733 sq yds}}{\text{1 city block}}\right)\left(\frac{\text{.07 worn tires}}{\text{lb. crumb rubber}}\right)$$

$$= \frac{\text{244 tires}}{\text{1 city block}}$$

These gross benefits are substantial; they are, however, misleading with respect to current tire asphalt rubber road repairs since the rubber currently used is but tread rubber ground from worn tires. In current tire asphalt rubber procedures many worn tires, less some tread rubber, remain to be disposed of. Current tire asphalt rubber repairs use 60 pound bags of tread rubber which were ground from 175 worn tires. The proportion, "n", above, for this procedure is 2.917; the number of tires used in a city block at this rate is 10,208; the gross benefit per tire drops to $.89 per tire in this case, and in addition, 8165 tires per city block repaired still remain to be disposed of. Without utilizing the entire amount of rubber available in the worn tire, the benefits of tire asphalt rubber, on a per tire basis, are much lower.

Cryogenics can be used to separate worn tires into three parts; rubber, metal, and fabrics so that virtually all of the tire rubber can be recovered. Steel belted radial tires are processed by cryogenics just as easily as non-steel belted tires. Cryogenics together with solid separation systems produces saleable metals and fabrics in addition: three pounds of steel and three pounds of fiber may be recovered for each waste tire processed. These provide additional gross benefits for the cryogenics/road repair alternative. Of course the costs of cryogenic processing must be included in the analysis in the appropriate place.

The three pounds (.0015 tons) of steel recovered is worth $.07 when valued at current prices of $45 per ton; no value data for the fibers recovered was available. The benefits of the tire asphalt rubber process, then, are B_{11} = 37.44 per tire per four years. This includes $37.37 costs avoided and interest savings plus .07 for recovered product values.

Each worn tire processed for use in tire rubber asphalt eliminates one waste tire and its associated processing costs. Waste processing costs are $.92 for a tire landfill (9). Consequently, the tire rubber asphalt alternative realizes an additional $.92 benefit per tire each four years.

The total road repair and decreased waste benefits for the road repair tire handling alternative, B_{11} = $38.36.

CALIFORNIA ROAD REPAIR BENEFIT CALCULATION

The asphalt rubber benefits are smaller according to California road repair practices and/or when treated in a more conservative fashion. Assuming that construction or reconstruction lasts ten years, conventional repairs last seven years, and asphalt rubber lasts ten years, Table D-2 was prepared.

This table probably illustrates the current perception of most highway repair officials with respect to the asphalt rubber process. It appears in any given year to be more expensive ($8661 versus $6366) and does not provide any benefit in terms of decreased costs. The present value (10%) of the costs for the two cases are approximately equal.

TABLE D-2. CALIFORNIA ROAD REPAIR COSTS

Year	Conventional 1 1/2 inch AC	Tire asphalt rubber 1" AC + 1/4" AR + 1/2" ACFC
0	86,000	86,000
10	6,366	8,661
17	6,366	
20		8,661
24	6,366	
30		8,661
31	6,366	
38	6,366	
40		8,661
45	6,366	
50		8,661
52	6,366	
59	86,000	86,000

The 1 1/2 inch asphalt concrete and 1 3/4 inch asphalt rubber repairs are not comparable, however. The asphalt rubber roads, as indicated above, have fewer reflected cracks. In addition the asphalt rubber repairs are fewer with less nuisance and accident hazards created. And, as indicated above, it may be that asphalt rubber lasts more than ten years. Consequently, we used the Arizona estimates in calculating the benefits of the asphalt rubber process. We investigated a lower conventional repair process cost ($R_C = 6366$) in both the framework of Table D-2 and of the formulas given.

LIMITS OF THE TIRE RUBBER ASPHALT PROCESS

The number of worn tires which may, potentially, be used in tire asphalt rubber repairs each year, in the United States, may be symbolically represented as:

$$T_W = 587 R_L R_W N_S$$

Where R_L = the mileage of cracked roads repaired, temporarily, each year (as opposed to rebuilt roads).

R_W = the average width, in feet, of a U. S. road.

N_S = the number of worn tires used in one square yard of tire asphalt rubber road repairs. $\frac{N_b}{A_b}$

* The constant 587 is used to convert the term "$R_L R_W$" to square yards.

Data on the mileage of temporary repairs carried out each year in the United States is not readily available. It is possible to gain insight on the market for the tire rubber asphalt repairs by a calculation of the number of miles which could be repaired with the two hundred million waste tires generated each year. To do this we set "T" equal to 200,000,000, assumed an average road width of 40 feet, and solved for R_L.

$$R_L = \frac{T_W}{587\ R_W N_s}$$

$$R_L = \frac{200000000}{587(40)(.065)} = 131,044 \text{ miles}$$

131,000 miles (210,821 kilometers) of road repair work will be needed each year to absorb all of the solid waste tires generated. United States streets and roads, in 1974, accounted for 3,815,807 miles (6,139,633 kilometers); almost all (3,000,000 miles or 4,827,000 kilometers) of these roads are asphalt. All of the worn tires currently generated could be used in the tire asphalt rubber process, assuming that a road requires repairs each three years, and that fifteen percent of these repairs are needed for fatigue type cracking of the sort controlled by asphalt rubber (10). If the average time between road repairs were five years, 90,000 miles (144,810 kilometers) per year would need repairs; for an average life of seven years, 57,500 miles (92,517 kilometers) per year would need repairs. It would appear, then, that tire asphalt rubber is potentially a fairly large scale process.

ALTERNATIVES TO ASPHALT RUBBER IN ROAD REPAIRS

Arizona found that not only asphalt rubber, but also four other processes control reflective cracking of highways.

TABLE D-3. ROAD REPAIR TREATMENTS VERSUS REFLECTIVE CRACKING.

1. Heater scarification and petroset	3
2. Tire asphalt rubber (between AC and ACFC)	4
3. Fiberglass	5
4. Heater scarification and reclamite	6
5. 200/300 penetration asphalt	8
Control sections	17

SOURCE: "Prevention of Reflective Cracking in Arizona Minnetanka-East, A Case Study", Arizona Department of Transportation Report Number 11, HPR-1-13(224) May 1976.

Petromat, is yet another product which seems to be in fairly high demand for road repairs. To the extent that any of these cost less than asphalt rubber an opportunity cost could be associated with use of asphalt rubber in the place of the best alternative.

Finally, highway repair officials are carrying out research on recycling road asphalt. Three alternatives: hot mix recycling, cold recycling with chemical options, and surface recycling are being investigated (11). It is possible that one of these may be desirable relative to asphalt rubber. Highway management officials should be convinced of the benefits of asphalt rubber; they should be consulted concerning a requirement for widescale use of the process; such a requirement would perhaps be very restrictive from their viewpoint.

APPENDIX E

100,000 MILE TIRES: PROFITS, PRODUCT SERVICE LIFE, AND SOLID WASTE MANAGEMENT

The design of manufactured products involves analyses and choices with respect to physical characteristics, marketability, performance, service life, maintainability, and other factors. Design factors may have offsetting effects; a better performance with respect to one factor may be detrimental to performance with respect to another. Product design balances the levels of achievement of these factors. Balance requires analysis of the costs and benefits associated with design alternatives in order to develop information on levels of achievement. Some costs and revenues (benefits) of conventional design analyses are internal to manufacturers. Other design costs and benefits are external to manufacturers; these affect consumers and society in general: Product design service life, for example, is proportional to (a) the quantities of solid waste generated; (b) the rate of use of fixed quantities of natural resources; and (c) the rate of cost to consumers for services provided by products. Costs and benefits affecting society in general have either not been included in product design analyses or have not been adjusted to reflect societal attitudes of the 1970s; perhaps they should be.

We analyze the internal and external costs and benefits associated with the design of passenger car tires. Longer service life appears to be not only a promising solid waste management alternative, but also promises: (1) improved total profits for the tire industry, and (2) a better deal for consumers.

COST TO CONSUMERS

Product design determines the cost to consumers, per unit of time, of the services provided by a product. One could say, disregarding maintenance and the time value of money, that a tire costing $60, which provides 4 years of service, costs $15 per year; should the tire last 10 years instead, the cost to the consumer would be only $6 per year. Service life design, together with sales price, determines this cost to consumers. In the current era of increasing inflation and cost consciousness, it is likely that consumers value increased product service life more highly. The comfort of a tire's ride, for example, a primary design criterion in past years, may have diminished in relative importance; the economics of service may today be more important. Product designers should take notice of changes in consumer needs. These changes can cause the optimal design balance to change.

SOLID WASTE QUANTITIES

In addition to consumer costs, design service life determines the solid waste quantities which pose problems and costs for public managers, engineers, and society. A tire could generate one worn carcass every 4 years, or one worn carcass every 10 years, depending upon its design life. Worn tire carcasses are costly and cause special problems in public waste disposal. The effects of product design lives upon the solid waste generation rate, and upon these costs, might also be taken into consideration in manufacturers' product design decisions. The increased requirements and costs of solid waste management may have, like the consumer service cost factor, changed the optimal product design balance toward longer service lives.

CONSERVATION OF RESOURCES

Design service life is related to the availability and use of nonrenewable natural resources such as oil. Short service life products use up fixed supplies of resources at a faster rate than do long service products. The world supply of petroleum (with consumption growing at the average annual rate of consumption prior to 1972) has been estimated to be adequate only through the year 1992 (12). Tires use petroleum in fair amounts:

(a) as a material ingredient in synthetic rubber production;
(b) as a material ingredient, and finishing medium, for tire cord yarn production;
(c) as an ingredient in the manufacture of carbon black for tire material;
(d) in rubber compounding (mixing the various types of rubber);
(e) as an energy source in production.

On the average, seven gallons (26.5 liters) of crude oil are used in the manufacture of a passenger car tire; this includes five gallons (18.93 liters) as a material ingredient and two gallons (7.57 liters) in the form of energy (13). While the 25,000 mile tire design uses 7 gallons of oil, for each tire, each 2.5 years, a 100,000 mile tire might use but 7 gallons each 10 years. Obviously, longer tire design service lives will conserve valuable oil resources; wire, fabrics, and other tire materials are similarly conserved by longer usage of the tire carcass. Longer service lives use valuable resources at a slower rate.

Some types of 100,000 mile tires will be heavier causing increased consumption of gasoline in autos. This effect does not negate the conservation benefit, however, but rather diminishes it.

Consumers' attitudes with respect to conservation and environmental quality have undergone well documented changes in the past decade. A great respect for conservation and environmental quality, including proper solid waste management, has developed. The new attitude is clear in the National Resource Recovery and Conservation Act of 1976. These changes in attitude affect consumer buying habits in the area of design service life; the current shift to the purchase of longer lived steel radial tires is evidence of this. Perhaps tire design service lives even longer than that of steel belted radials are desirable to consumers.

THE 100,000 MILE TIRE

The socially conscious manufacturer may respond to these factors by recomputing the optimal balance among the factors important in product design. It would seem, however, that increased design service lives portend drastically decimated markets and profits. These are contrary to the manufacturers' primary task which is to survive and to obtain healthy profits. With this realization, tire manufacturers avoid the longer service life idea via the mystique of technical infeasibility. Who would propose a 100,000 mile tire! But what if longer product service lives, and healthy profits for the tire industry can together be realized? What if consumers want 100,000 mile tires? And what of future society where radically improved service lives may be a reality, not by management choice, but due to resource limitations and solid waste pollution?

We find that longer lived products can provide the same level of total profit to the tire industry, can be more economical to consumers, and, at the same time, can conserve resources and decrease waste quantities. Further, we believe consumers will want them when all the facts are known.

100,000 MILE TIRES: TECHNICAL FEASIBILITY

It is technically feasible to manufacture passenger car tires which will last on the average, under normal conditions of use and recommended inflations, 100,000 miles (160,900 kilometers). Truck tires, in current practice obtain 115,000 (185,035 kilometers) of original life before the first retreading (14); truck tires are designed differently than passenger car tires, however; they use different rubbers and are of different dimensions. Consumers, when made aware of the 100,000 plus mile truck tire life could demand tires designed to be similar to truck tires. They could, in some cases, buy currently available truck tires.

Design Factors Controllable By Tire Engineers

Tire design engineers have at least six basic design factors under their control which could be used to improve passenger tire service life (15):

1. Tread compound - the recipes for tread rubber may be adjusted by type and percent of elastomer, type and percent of carbon black, type and percent of oil extenders, dispersion, and state of cure.
2. Tire construction type - bias, radial, or bias belted designs may be chosen.
3. Tread pattern - the number of ribs, groove width, element geometry, unit tread pressure, type blading, skid depth, footprint area may be changed.
4. Mold shape - the shape of the mold used in vulcanizing may be altered.
5. Tire dimensions - diameter, tread width, aspect ratio, tread radius may be changed.
6. Tire fabric - (in either the carcass or belt) cord size, cord count, cord processing, composite, cord angle, number of plies, lay up may be changed.

Clearly, there are numerous combinations of factors from among these which might be investigated with the idea of extending the average tire service life to 100,000 miles (160,900 kilometers).

Three Alternative Designs For 100,000 Mile Tires

Three technological alternatives for the development of 100,000 mile passenger car tires are listed below.

1. Large High Pressure Tire (LHP). Redesign autos to use the larger tire sizes; increase operating pressure in the tire; and redesign the automobile suspension system to absorb some of the increased harshness of the ride.

2. Thick Tread-Wide Tire (TTW). Use truck tread rubber, increase the thickness of the tread rubber on conventional passenger steel belted radial tire carcasses, to the maximum safe thickness; widen the tire as in current sportv wide tires.

3. Durable Tread Rubber (DTR). Develop a highly durable tread rubber which, with the same tread thickness as in current passenger tires, and at the same low inflation pressures as have current tires, will obtain 100,000 miles (160,900 kilometers).

There are, in addition, other alternatives, as indicated above. We examine the LHP and DTR tires briefly below. The TTW tire is then examined in detail.

The LHP 100,000 Mile Tire

The Large High Pressure Tire (LHP), contrary to popular belief, is technically feasible.

> "If autos were redesigned to make it possible to fit them with much larger tires, then 100,000 miles is possible with no new developments. To illustrate, assume a 3600 lb vehicle, 900 lb on each tire. A 6.95-14 tire is rated to carry 1050 lb and on this vehicle would be carrying only 86 percent of its maximum load. Let's replace that tire with a 8.85-14 tire which can carry 1580 lb...That tire is carrying 57 percent of its maximum load. This change would increase the service life from 40,000 to perhaps 65,000 to 70,000 miles. If we increase inflation pressure from 24 psi to 40 psi, the load bearing capacity of the larger tire would be increased to 2100 lb and the load would be 43 percent of the maximum safe load and the tread life would probably exceed 100,000 miles." (16)

The costs associated with the LHP tire would include the incremental purchase costs of the larger tire as well as some one time costs associated with vehicle and tire production:

> "The larger sized tire requires changes in fenders and axles, in steering systems; high pressure tires would require new suspension systems that would be capable of filtering out high frequency road induced vibrations which the tire now absorbs. If I am correct, there is no problem as far as the tire is concerned; it is the vehicle that must be modified. As the tire company representatives point out, they respond to auto manufacturers' requirements and if they change the vehicle design these solutions are available." (16)

The DTR 100,000 Mile Tire

The Durable Tread Rubber Tire (DTR) is, evidently, not yet technically feasible. The idea here is to maintain the current size, shape, and operating characteristics but to replace the tread rubber with a highly durable elastomer that will last 100,000 miles (160,900 kilometers).

Plastic tires have been molded by the tire industry, but have not been commercialized. Rubber, with such excellent wearing properties as with plastic may be limited in performance with respect to traction. The tire industry has carried out a survey of its experts and has estimated that there is greater than a fifty percent chance that the durable tread rubber with adequate traction capabilities will be developed by 1990; according to the survey some experts thought that 100,000 mile DTR tires might be available as early as 1983 (17). According to the experts, then, DTR 100,000 mile tires are destined to appear in the not too distant future, but are not yet technically developed.

The TTW 100,000 Mile Tire

The TTW tire offers an alternative to the largeness and higher operating pressure of the LHP 100,000 mile tire. TTW 100,000 mile tires are technically feasible as we see below.

A simple means of obtaining 100,000 miles (160,900 kilometers) from passenger car tires would be to increase the tread rubber depth by an amount proportional to the desired mileage. Steel belted radial tires, prior to the general decrease in the speed limit to 55 miles per hour (88.5 kilometers per hour) obtained on the average 38,000 miles (61,142 kilometers). There should be a 10 percent increase in mileage with a 10 mile (16.1 kilometer) decrease in the speed limit assuming that one half of U. S. driving is done on highways affected by the change so that steel belted radials should now obtain around 41,800 miles (67,256 kilometers). We used a conservative figure of 40,000 miles (64,360 kilometers) for the average service life of a 1977 steel belted radial passenger car tire. We noted that 100,000 is 2.5 times 40,000. If the relation between tire service life and tread thickness is linear, then 2.5 times the current tread thickness is required for a 100,000 mile tire. We propose initially, then, to increase the passenger tire tread rubber thickness by a factor of 2.5; the following sections will demonstrate, however, that only a thirty-four percent increase in tread thickness will be needed for 100,000 mile TTW tires.

Passenger Tire Tread Rubber Thickness

Tire industry personnel commonly represent tread rubber thicknesses in thirty-secondths of an inch. Table E-1 indicates current thicknesses of tread rubber used by retreaders for passenger and truck tires.

TABLE E-1. 1977 TREAD RUBBER DEPTHS

Tire type	Tread thickness			
	Uncured		Cured	
	Cm	Inches	Cm	Inches
Passenger cars, conventional	0.95	12/32	0.87	11/32
Passenger cars, snow and mud	1.11	14/32	0.95	12/32
Truck tires, highway or rib	1.58	20/32	1.43	18/32
Truck tires, lug design	1.91	24/32	1.75	22/32

SOURCES: (1) Mohawk Rubber Co., Akron, Ohio letter of February 23, 1977 from R. W. Eckard to R. Westerman.
(2) Oliver Rubber Company, Oakland, California letter of February 22, 1977 to R. Westerman.

Thicker treads than the 14/32 inches and 24/32 inches indicated are manufactured for specialty applications such as the "Highway Rib Extra Tread" truck tire, for taxi tires, and for passenger snow tires. Taxicab tires have utilized extra thick tread rubber in original manufacture together with regrooving, cutting a new tread pattern into the tire when the first is worn off. These specialty tires are limited to a general speed of, perhaps, 40 miles (64 kilometers) per hour with short (20 minute) spurts to 50 miles (80 kilometers) per hour. Maintaining higher speeds for longer periods is reported to cause heat buildups in the tires which may cause damage to the tires.

The thick tread rubber alternative for 100,000 mile tires would indicate that a tread rubber thickness of 27.5/32 inches (2.2 cm) cured would be necessary; this is 2.5 times the cured thickness used for conventional passenger car tires. The truck designs indicate that as thick as 22/32 cured inches (1.75 cm) may be used, yet this is for generally larger tires. Truck tires, however, use different tread rubbers than do passenger car tires:

> "Service conditions are more severe for truck tires, therefore the rubber is generally tougher than for passenger car use." (18)
>
> "Should a good truck grade of rubber be used on a passenger tire it would produce mileage equal to or in excess of new tire mileage." "Truck tire compounds...are of higher quality." Truck fleets who do keep records...insist on the highest qualities of rubbers." (19)

It seems, then, that less than 27.5/32 (2.2 cm) inches of tread rubber will be needed for a 100,000 mile tire if truck tread rubber is used.

Another factor bearing on the thickness of the tread rubber needed for a 100,000 mile tire is the wear rate:

> "Bias tires wear at a logarithmic rate indicating decreasing wear with increasing mileage. This decrease in wear rate can be attributed to a progressively increasing tread radius and to the tread elements which become more rigid with wear and thus, do not exhibit as much movement through the ground contact area." (20)

These same factors, increasing tread radius and increasing rubber rigidity with wear, should be at work in steel belted radial tires. Consequently the tread rubber required for a 100,000 mile tire, based upon this factor alone, would be less than the quantity indicated by the direct proportion taken above, 27.5/32 inches (2.2 cm); as the design service life is increased the additional tread rubber required is in less than a linear proportion.

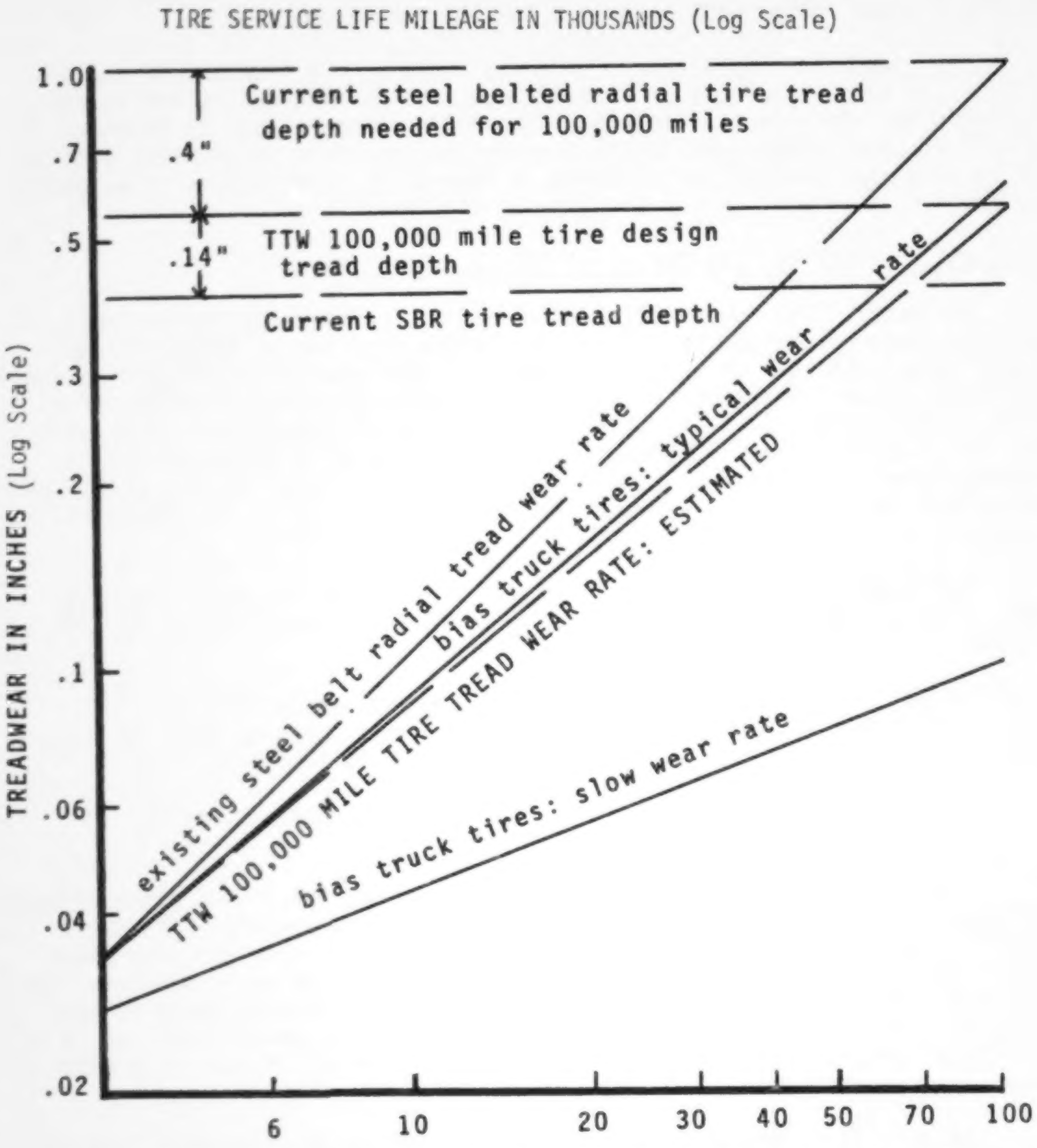
Figure E-1 may be used to explore the tread rubber thickness needed when both (1) the use of truck tread rubber, and (2) the logarithmic wear rate are taken into consideration. Figure E-1 indicates that, to obtain 100,000 miles from a truck tire, .62 inches of truck tread rubber would be needed under typical wear conditions and .1 inches under slow wear conditions; these figures are for bias truck tires operating at much higher pressures, however.

We plotted estimated passenger car tire lines on Figure E-1. Manufacturers now offer tires guaranteed to last 50,000 miles. To this basic steel belted mileage we added twenty percent based upon the wide tire concept:

> "...the ultra-wide radial is reported to give 20 percent more tread wear than a regular radial tire which is already far better than a conventional bias ply tire. In addition, it gives better high speed performance because of the additional rubber on the road. It does not give any cornering trouble as ordinary radials sometimes do at high speeds." (21)

This resulted in a steel belted radial tire expected life of 60,000 miles. We assumed that the effect of the general decrease in the speed limit to 55 miles per hour, a 10 percent advantage, perhaps, in tread wear over the older high speed limits, had been included in the 50,000 mile guarantee manufacturers' boast.

The effect of using truck tread rubber in lieu of passenger tread rubber could be estimated to increase mileage by as much as sixty percent. "The average mileage obtained from a retreaded radial (steel belted) is 25,000 to 40,000 miles depending on the type of tread rubber used." (22) We allowed, however, that the selection of the highest quality of truck tread rubber would increase mileage of our TTW tire a modest ten percent, to 66,000 miles. We placed a point on Figure E-1 at the point where 66,000 miles intersects with the current design depth .41 inches, and connected this point to the common



Note: this figure is based upon Davisson, "The design and application of commercial type vehicle tires", p 28, Fig. 39.

Figure E-1. Tire service life versus treadwear.

point of the two truck tire lines as an origin to establish an estimate of the TTW 100,000 mile tire tread wear rate line. The TTW 100,000 mile tire tread wear rate line. The TTW line indicates that about .55 inches (1.397 cm) of truck tread rubber will be needed for 100,000 miles.

This represents an increase in tread depth of .14 inches (.34 cm) or 4.5/32. A total thickness of 17.6/32 inches of truck tread rubber is required. This thickness is less than the 20/32 commonly used by trucks. If 4.5/32 of truck grade quality tread rubber can be added to the best quality ultra wide steel belted radial tires, a feat which seems realistic according to Table E-1, we will have a TTW 100,000 mile tire.

Strength, Durability, and Safety of 100,000 Mile Tires

The extra tread rubber will, after a certain thickness is reached, however, undergo heat buildups which may cause the tire to fail. In addition, tires with such thick tread rubber may not handle as well as do current passenger tires. There are questions of safety associated with the thick tread rubber tire. In fact, there are questions of safety associated with any tire designed to go 100,000 miles. Can a tire carcass--as well as a thicker tread--last through 100,000 miles of road hazards such as stones and potholes? We examine these questions in order to establish the technical feasibility of 100,000 mile tires.

The carcass of existing steel belted radial tires has been judged by some tire industry personnel to be adequate for a service life of 100,000 miles:

> "In analyzing the tire, the carcass is probably adequate"... (for 100,000 miles)..."since it is already retreaded and generally performs well even in two retreads for many." (23)
>
> "There is no problem as far as the tire is concerned; it is the vehicle that must be modified." (24)

There is no mention, in the tire literature, of the tire carcass deteriorating with age, except for the problem of sidewall cracking. Sidewall cracking is a chemical reaction via which cracks develop in the tire sides over time, generally after six years. Sidewall cracking is an aesthetic problem, not a cause of tire failure. Even if sidewall cracking would be more serious sidewall rubbers which can eliminate this problem are reported to be available; anti-oxidants can be compounded into sidewall rubber to accomplish this.

The ability of any tire to withstand 100,000 miles of service life including encounters with road hazards has been questioned (25) The notion that a 100,000 mile tire has to "survive" 2.5 times as many potholes, rocks, and other road hazards implies that: (1) an average driver routinely encounters a significant number of road hazards, and (2) tire rubbers become weaker, and more susceptible to damage from road hazards, with age--or with each encounter and (3) these factors will be significantly detrimental to the safety of 100,000 mile tires--perhaps causing injuries and death. None of these implications hold any obvious or absolute truth. The number of road hazards is relatively small; drivers are not constantly running into rocks, potholes, and nails. Encounters with road hazards are the exception rather than the rule.

There is no indication in the literature of tire rubbers or tire structure weakening with age. We have already reported the contrary with respect to tread rubber; tread rubber actually becomes harder with age. And it seems that repeated encounters with road hazards should only cause tire failure if: (a) the tire was of poor manufacture in the first place; or (b) the road hazard encounters are of such extent that they could be labelled "abuse".

Some factors related to manufacture which might, together with road hazards, cause a tire related accident are (26):

bead deficiencies - inadequate insulation, improper splicing; too small diameter; inadequate or no Chafer
ply deficiencies - inadequate adhesion between plies, defective splicing, contaminants at interfaces, cord breaks
tread deficiencies - inadequate adhesion, air entrapment, contaminants at interface of tread and carcass
inner liner deficiencies - too thin, inadequate composition, air entrapment
hinge points - abrupt changes in structure such as belt ends
defective cords - inadequate materials, size, and strength; contamination; overlapping too much; frays.

It is probably true that the additional 60,000 miles of tire service life of a 100,000 mile tire, in combination with the manufacturing defects listed above, would cause increased incidence of tire failures; we suggest, however, that the tire industry inspects and tests to avoid poorly manufactured products since who is to say that defects might not cause death and injury during the first 40,000 miles of a tire. Recently, however, it has been suggested that all current tires are defective (27).

Quite to the contrary of the explanatory approach taken above, we feel that 100,000 mile tires will be significantly more safe than current tires. Tires are not known to be a significant cause of accidents and injury; that is, of course, unless the tires in question were bald, devoid of tread. Tire manufacturers have claimed that only .057 percent of vehicle accidents are tire related. Bald tires, whether 100,000 mile design or 40,000, will be dangerous when exposed to road hazards. Studies indicate that (1) bald tires are more susceptible to damage, and that (2) older cars are more prone to be fitted with bald tires:

> "There is evidence of significantly greater hazards of both tire failure and accidents with bald tires. Tread depth remaining on tires decreases with vehicle age...Based upon a sampling of the general population of...tires in the USA it appears that one-eighth of the passenger car tires in service are bald." (28)

100,000 mile tires would eliminate much of this danger, due to baldness, during the last five to seven years of a vehicles life. 100,000 mile tires would not be likely to become bald until, on the average, 100,000 miles of service, 10 years of life, was completed. 100,000 mile tires would have a substantial amount of tread remaining during the last five to seven years of use whereas current tires do not. 100,000 mile tires, then, should be safer than current tires. They will decrease the incidence of accidents and provide benefits to society in terms of lives saved, reductions in property losses, and reductions in personnel and paperwork now needed to account for accidents.

The LHP 100,000 mile tire would be an even more safe tire since it would be underloaded, operating at higher pressures with less deflection, and would have more body plies. The decreased deflection would be especially important to increased safe life of the tire.

Even if this were not so, safety technologies are readily available to tire manufacturers, technologies with which any tire can be made virtually accident free. These designs could be combined with the 100,000 mile designs above to provide increased safety:

> Self Sealing Tires - usually a tacky coating on the inner liner surface which has the characteristic of "healing" a puncture would even in the event that the puncturing object is expelled from the tire.
>
> The Tire Within A Tire - tires designed to be operable even if totally deflated, and still maintain reasonable highway speeds for long distances with total vehicle control, and the avoidance of destructive damage to the tire.

Traction, the ability of a tire to enable the vehicle to remain under control on a road, may be affected by the 100,000 mile design. For the TTW tire, if truck or high quality tread rubber were to have less traction than current passenger tire tread rubbers, then 100,000 mile tires would not handle quite as well. Yet the TTW tire is ultra wide with a larger footprint and this factor, if necessary, could offset the traction effect of the tread rubber used. And traction problems related to accidents are generally caused, again, by baldness. 100,000 mile tires will not be bald for the greater part of ten years. Traction, it would appear, could be about the same as with current passenger tire design, or better. Obviously, however, the traction factor should be given careful consideration in the detailed design stage for 100,000 mile tires.

In summary, it appears that 100,000 mile tires, both the LHP and TTW designs, can be more durable, strong, and safe than current 40,000 mile tires. We examine next, marketability.

MARKETABILITY OF 100,000 MILE TIRES

Consumers will buy 100,000 mile tires; in a preliminary market survey, virtually all of the respondents indicated that they (1) were interested in such tires and (2) were willing to pay from $30 to $150 additional for each tire (29). There are several reasons for this interest:

1. Consumers can obtain 100,000 mile tires when they buy a new car and can, conveniently and accordingly, include ten years of tire costs in the financing of the new vehicle.

2. Consumers can obtain 100,000 mile tires at a price which, in present value analysis, is cheaper than the costs of the alternative four sets of tires. Consequently consumers achieve a lower cost per mile.

3. 100,000 mile tires will provide added safety to their own vehicle and to the vehicles with which they interact on the road.

4. Purchase of 100,000 mile tires will eliminate the need for at least three distasteful trips to purchase replacement tires; this will include gasoline savings, time savings, and avoidance of the confusion associated with tire brands and types.

5. Consumers can recoup their investment if they sell their car after, say, three years; the factor of having good tires with 70,000 miles of treadwear left will be an asset which will increase the resale price.

6. Consumers can avoid public costs (increased taxes) associated with waste tire disposal. Waste tire disposal involves, at the least, transportation costs, expensive shredders costs, and landfill costs; 100,000 mile tires eliminate 75 percent of the waste tires generated in any year, and, accordingly, avoid 75 percent of the public tire waste costs.

7. Consumers are very much conscious of the needs for conservation and protection of environmental quality. They will buy 100,000 mile tires because they believe in the need for conservation and they value quality of the physical environment.

The costs to consumers may be, with the LHP 100,000 mile tire, a relatively harsh ride. The principal factor in passenger car tire design has been riding comfort:

> "The original inventors and pioneers of the pneumatic tire were inspired by the one objective of cushioning a moving vehicle. The tire has evolved to provide many other essential properties for the operation of modern vehicles, but the principle of a soft smooth ride remains a major criterion and will probably remain the governing factor in design approaches in the future." (29)

Tire manufacturers would say that, "Consumers, through their automobile purchases demand tires that ride soft; consumers will not buy rougher riding tires such as LHP tires". We suggest that consumers may not even notice the difference in ride between 100,000 and current belted tires. We suggest, further, that oil quantity limitations, inflationary cost increases, and solid waste pollution have, perhaps, changed consumer attitudes more toward a tire product design balance which is more economical in use and which conserves oil and avoids pollution and public waste handling costs. The consumers of today will buy 100,000 mile tires, even if their ride is rougher.

The preliminary design analysis, above, shows that 100,000 mile tires are technically feasible; there are significant bases upon which to build a marketing campaign. Why is it then that the tire industry has not already produced 100,000 mile tires?

A TIRE INDUSTRY VIEWPOINT: 100,000 MILE TIRES

The Rubber Manufacturers Association indicates that the tire industry is booming; the replacement tire market has grown by leaps and bounds (30).

TABLE E-2. U. S. PASSENGER TIRE SALES (SHIPMENTS) IN MILLIONS

Market	Year					
	1950	1955	1960	1965	1970	1975
Original equipment	37	43	36	51	38	40
Replacement	47	50	69	95	133	129*

* The 1975 figure was affected by a fairly severe recession.

Is it not "just good business" to keep tire service life short as compared to vehicle life; after all, repeat sales mean repeat profits. This approach has resulted in the fantastic growth in Table E-2. The larger the annual market volume, the larger the annual profits. 100,000 mile tires will be, of necessity, original equipment (OE) tires and, except for defective or damaged 100,000 mile tires and to replace short lived tires already in use, there will eventually be little or no need for a replacement tire market. 100,000 mile tires have little appeal when viewed from this viewpoint, the current viewpoint of the tire dealer.

Price research has indicated that tire manufacturers now make substantial profits (6 or 7 percent) on replacement tires with little or no profit (1 or 2 percent, sometimes even losses) taken on original equipment sales. The apparent strategy of this approach is to build up the company name and image in the original equipment market so as to promote replacement tire sales and an increasing market share of the replacement market. Consequently, manufacturers would have to sell 100,000 mile tires to automobile manufacturers at higher prices than those of current practice. Can tire manufacturers convince automobile manufacturers to buy 100,000 mile tires? Can they take, with this product, reasonable recurrent profits? Can enough profit be obtained so as to maintain the current value of the industry? And what of the job changes and losses associated with the lost market volume? What will be the effects on employment levels and the national economy? Conventional economic theory as well as political insight indicates that responses to these questions should be negative. Tire dealers and manufacturers have not produced 100,000 mile tires because it seems, to them, a matter of survival. This is a quite different reason, however, than the usually assumed non-availability of technology to do the job.

We would respond to these questions facing the tire and auto industries positively: Consumers will buy 100,000 mile tires and therefore automobile manufacturers will purchase them for original equipment. We indicate below how the tire industry can actually make greater total profits per year with 100,000 mile tires. According to conventional economic theory then, there should be an improvement in the national economy with a greater Gross National Product as 100,000 mile tires become standard.

The last hard question relates to employment levels. With 100,000 mile tires, fewer manufacturing, transportation, and sales employees will be needed. With the TTW tire, for example, we would produce, in 1975, for example, thirty-five million 100,000 mile tires for original equipment. We would produce, in addition, the 138 million conventional replacement tires or 138 million 75,000 mile tires, or 138 million of some other design service life tire. The effects of the 100,000 mile tire should be felt that year in a positive fashion as more workers should be needed to produce the same number of tires as would ordinarily be required, but to produce tires of higher service life quality with more materials and some increased labor. The next few years should be of similarly high employment. After, perhaps, four years, however, the demand for replacement tires will begin to decline; tires that ordinarily would require replacement that year will not require replacement. The replacement tire market will continue to decline in volume over the years, the only growth influence being attributable to population and car sales growth. Some persons employed by the tire industry during this time would, of necessity, have to change to other jobs or products. Tire salesmen might have to focus upon auto accessories. Tire dealers might have to focus more upon auto and tire service.

These changes are not unusual in the tire industry. Since the 1960s choices of reinforcing fabrics, wire, and glasses, used in tires, as well as materials used in elastomer compounding, have shifted the fortunes of company after company. The recent shift toward increasing use of 38,000 mile steel belted radial tires has placed into effect, as a profit oriented business decision, the exact effects which we forecast for the 100,000 mile tire: Although it is difficult to discern in the total figures of Table E-2, long life radial sales are booming in their initial years. Tire dealers are shifting more toward being automobile service centers. The 100,000 mile tire proposal promises more of the same.

The notion that the effects of 100,000 mile radial tires would be felt gradually over times is demonstrated in Tables E-3 and E-4, the results of a simulation of car and tire production and solid wastes (31). The results of a hypothetical Federal Policy requiring that, all new cars sold in 1978 and thereafter be equipped with lifetime, 100,000 mile, tires," were as follows:

TABLE E-3. SIMULATED WASTE TIRES AND NEW REPLACEMENT TIRE SALES IN 100,000's: 1960 THROUGH 1990

Year	New cars produced	Waste tires model run (1)	(2)	Repl. tire sales model run (1)	(2)	Junked cars
1960	63	1170	1170	990	990	36
1961	65	1280	1280	1025	1025	51
1962	67	1230	1230	1020	1020	42
1963	69	1260	1260	1095	1095	33
1964	71	1410	1410	1170	1170	48
1965	74	1455	1455	1200	1200	51
1966	76	1530	1530	1265	1265	53
1967	78	1535	1535	1280	1280	51
1968	80	1670	1670	1380	1380	58
1969	82	1655	1655	1345	1345	62
1970	85	1770	1770	1450	1450	64
1971	87	1760	1760	1435	1435	65
1972	89	1890	1890	1545	1545	69
1973	91	1890	1890	1595	1595	59
1974	93	1920	1920	1565	1565	71
1975	96	2060	2060	1685	1685	75
1976	98	2000	2000	1610	1610	78
1977	100	2115	2115	1730	1730	77
1978*	102	2070	2070	1670	1670	80
1979	104	2205	2205	1860	1860	69
1980	107	2010	2030	1645	1645	77
1981	109	2245	2060	1785	1595	93
1982	111	2030	1700	1575	1245	91
1983	113	2165	1535	1735	1095	88
1984	115	2130	1320	1645	860	92
1985	118	2340	1290	1865	825	93
1986	120	2215	1090	1745	645	89
1987	122	2370	1045	1930	585	92
1988	124	2305	1100	1755	570	106
1989	126	2590	1090	2005	505	117
1990	129	2460	1035	1890	470	113

* Model Run 2 implements the policy of all 100,000 mile tires on original equipment cars, and 27,000 mile retreaded tires for replacements, beginning in 1978. These figures were taken for a single computer run; they suffice for a rough indication. Follow up research should sample from this model to obtain average results.

(1) No effects were felt on replacement tire sales for two years; actually, as above, more workers and labor would be involved, increased employment and GNP, to produce this expected number of tires.

(2) Beginning in 1981, replacement tire sales begin to diminish at an average rate of 11,750,000 per year, to a level of around 47,000,000 tires per year in 1990; these sales should continue to decrease as the needs for replacements drop to near zero eventually and used and retreaded tires could fill these needs.

(3) New cars produced increase from 10,200,000 in 1978 to 12,900,000 in 1990. New OE tire sales increase by about 1,000,000 tires per year.

The important points that we would make are that the replacement tire market still exists after ten years, and that it has been decreasing over time at a rate of 11,750,000 tires per year. There is no elimination of the replacement market all at once as some would fear. Meanwhile the new passenger tire market is increasing by one million tires per year.

The 100,000 mile tires being produced will require, in addition, more labor and materials, and higher per tire employment levels than current tires. If the increase in labor and materials is linear, then there will be no employment decreases whatsoever with 100,000 mile tires; all of the labor and materials that went into replacement tire production would be merely shifted to OE tire production. This is not the case however--it is much cheaper to produce and sell one 100,000 mile tire ($30) than it is to produce four current steel belted radial tires ($80). 300,000 persons are employed by tire manufacturers and dealers. If 100,000 mile tires are used as original equipment, then 5/8 of these, 187,500 persons, might be expected to be affected during a, perhaps, fifteen year period. This amounts to about 12,500 persons per year whose employment will be affected. These persons will include tire builders and other manufacturing personnel, tire dealers, and tire salesmen. If these are split evenly between production and sales, then 6250 persons per year in each category can be expected to be affected. Retreaders, reclaimers, and tire splitters should still have an adequate number of worn carcasses to work with as well as adequate markets.

Some of the 6250 persons per year may be able to continue employment in the same job due to increased demand for new cars. Others may have to find new employment. Perhaps the necessary employment shifts can be managed by tire manufacturers and dealers so that affected employees have years of notice, have retraining, and are given placement services by their firms.

None of this needs to affect the gross value of the tire industry; this is demonstrated in the following section. Tire prices can be established so that gross profits from one 100,000 mile tire can be greater than or equal to gross profits from four 25,000 mile tires. This can actually be accomplished with the tire consumer receiving tire services for less cost per year.

TABLE E-4. ESTIMATED PASSENGER TIRE SALES DATA 1981 - 1990

Sales data in 100,000's

Year	(1) Exp. OE sales	(2) Exp. rep. sales	(3) Exp. total sales	(4) Actual rep. sales	(5) Exp-act rep. sale decrease	(6) Act rep decrease from prev year	(7) OE increase over prev year	(8) Net an dec 6-7	(9) Net tot dec 6-7
1981	545	1785	2330	1595	190	50	10	40	180
1982	555	1575	2130	1245	330	350	10	340	320
1983	565	1735	2300	1095	640	150	10	140	630
1984	575	1645	2220	860	785	235	10	225	775
1985	590	1865	2455	825	1040	35	15	25	1030
1986	600	1745	2345	645	1100	180	10	170	1090
1987	610	1930	2540	585	1345	60	10	50	1335
1988	620	1775	2375	570	1185	15	10	5	1175
1989	630	2005	2635	505	1500	65	10	55	1490
1990	645	1890	2535	470	1420	35	15	25	1410

*NOTE: This is Actual Replacement Sales geven the requirement that all OE tires be 100,000 mile tires.

We examine next the costs, prices, and profits of 100,000 mile tires.

COSTS, PRICES, AND PROFITS: 1976 STEEL BELTED RADIAL TIRES

100,000 mile tires will, obviously, cost more than current passenger tires. The TTW Design is based upon the steel belted radial carcass and its estimated costs may be determined in relation to current steel belted radial tires; to the basic cost of a current steel belted radial, we can add the increased costs for labor and materials--as well as a reallocation of overhead costs. Estimates of current manufacturing costs provide the basis for our estimates of 100,000 mile tire production cost.

Steel belted radial tire manufacture is relatively new in the United States; there are two basic methods of steel belted radial tire manufacture: these are the conventional, "Single Stage" method, and a, special for steel belted radials, "Two Stage" method. The Two Stage method requires an extra machine (the second stage) for tire building; the second machine expands the green tire to its torroidal shape so that the relatively inflexible belts may be added. In the One Stage method more flexible belts are added prior to expansion to final shape.

We estimate that steel belted radial tires, in 1976 production, exhibited the following cost and price relationships:

TABLE E-5. COSTS AND PRICES OF STEEL BELTED RADIAL PASSENGER TIRES

	Two-stage steel belted			One-stage steel belted		
Manufacturers' prices[*]						
OE auto cost of a tire	22.11	27.64	33.17	17.69	22.12	27.06
REP dealer cost of a tire	22.91	28.64	34.39	18.32	22.91	27.51
Retail tire dealer sales price[&]	39.20	65.50	89.60	39.20	65.50	89.60
Gross profit: dealers[¢]	16.29	36.86	55.21	20.88	42.59	62.09
Tire dealer expenses[#]	15.31	34.64	51.89	19.62	40.03	58.36
Net (BT) profit: dealers[@]	.98	2.22	3.32	1.26	2.56	3.73

[*] Manufacturers' costs were calculated based upon a range of belted bias costs of $12 to $18; we used three discrete levels: $12, $15, and $18. To this we added 25% for the two stage process; nothing was added for the single stage process; this represented a 25% and 0% incremental cost for radial tire production over bias belted. Next a 40% increase in costs over the calculated radial tire cost was figured in; this increase represents the oil and associated price increases of 1974 to 1976. The labor price increase of late 1976 was next figured in at 12% times the labor portion of tire costs .275. Then 2% OE manufacturers profits and 6% replacement tire manufacturers profits were added. References are (1) Westerman, pp 176-179; (2) Cox, NTDRA Marketing Guidelines, 1977, p 11; (3) Cone, et al, p 75; and (4) Modern Tire Dealer, 1977, January, p 72.

[&] Reference Cox, NTDRA Marketing Guidelines 1977, p 11; these are actual prices for the first six months of 1976, with 12% added to reflect the settlement of the labor dispute of 1976--Modern Tire Dealer, January 1977, p 72.

[¢] Profits on original equipment were not calculated. This gross profit represents retail price minus replacement tire cost; this assumes that low cost tires are sold at lower prices.

[#] Expenses were calculated at .94 of gross profit; reference Cox, NTDRA Financial Analysis Study 1977, p 2, Table 2.

[@] This before tax profit was calculated as gross profits minus expenses. Taxes would be .25 or .48 percent of this, depending on the size of profits.

The cost figures given for the one stage process are probably better estimates of radial tire manufacturing costs:

> "Radials sell for up to 50% more than other tires, yet cost little more to manufacture, especially now that Akron's "learning experience" is largely completed and radial volume is moving into mass production figures." (32)

A breakdown of total passenger tire costs was developed by Cooper (33):

TABLE E-6. PERCENT OF PER TIRE MANUFACTURING COSTS, BY CATEGORY

Cost category	Bias belted glass/textile	Radial textile/textile	Radial steel/textile
Investment	9	8	10
Labor	39	45	45
Materials	52	47	45
Total	100	100	100

In 1976 another cost breakdown for steel belted radials was reported: (1) Labor 10%; (2) Materials 50%; and (3) Other 40%; profit was not included in this estimate (34).

This discrepancy in reported data (10% labor versus 45% labor for steel belted radial tires) is probably based upon accounting practice; the later estimate reflects the recent investment in radial tire production equipment in its high depreciation years and consequently the "Other" category including depreciation expense is relatively high, 40%. Cooper's figures, on the other hand, probably reflect little depreciation expense and, perhaps, could more fairly be called "overhead". Cooper's sources may not have realized the affect of decreased production quantities on overhead; fewer tires per year are needed with radials. We used the average of the two reports as our estimate. We felt that this was a more accurate representation of the long run proportions.

TABLE E-7. SBR PER TIRE PRODUCTION COSTS BY CATEGORY

Cost category	Percent of total costs
Overhead, S_o	25.0
Labor, S_L	27.5
Material, S_m	47.5
Total	100.0

We estimate next the additional materials, labor, and overhead needed for a 100,000 mile tire.

100,000 MILE TTW TIRES: INCREMENTAL MATERIALS NEEDS (H_m)

If the incremental material needs for a 100,000 mile tire were in proportion to the mileage obtained, then 2.5 times the materials of a current steel belted radial tire, an increment of 1.5 times the materials, would be required:

$$\frac{M_6}{M_1} = \frac{100000}{40000} = 2.5$$

$$\frac{M_6}{M_1} - 1 = 1.5$$

Where M_6 = the mileage obtained, on the average under normal use, from 100,000 mile tires.

M_1 = the mileage obtained, on the average under normal use, from current steel belted radial tires.

We have indicated, however, that the carcass of an existing steel belted radial passenger tire is adequate for 100,000 miles (160,900 kilometers) of life, and that only 4.5 thirty-secondths of an inch (.36 cm) over the usual 13.1 thirty-secondths of an inch (1.04 cm) of tread rubber thickness will be needed. The additional tread rubber needed represents an increment, not of 150%, but of only 35%. Tread rubber constitutes perhaps fifteen percent of the tire materials by volume. Accordingly we multiplied the increase in depth (.35) times the proportion (.15) to determine the increased materials proportion; the result is a five percent increase due to tread rubber thickness:

Increased Tread Rubber Needs = D_t (D_h) = .15 (.35) = .05

Where: D_t = a decimal fraction; the fraction, by volume, that tread rubber constitutes of a tires materials

D_h = the decimal fraction increase in tread rubber depth needed for 100,000 miles of tire service life as opposed to 40,000 miles

This tread rubber would be truck tread rubber in lieu of passenger tread rubber. We represented the truck tread rubber as rubber comprised of a higher grade of carbon black than is currently normal. The higher quality carbon black costs more, we assumed a twenty-five percent increase, than that currently used for passenger tires, but requires less black and less oil extender; the amount effect is a cost savings of about eleven percent. (34) If these figures are reasonable, then the net effect would be a fourteen percent increment in the cost of tread rubber .

Net Increase In Materials Due To Quality = D_q - D_d = .25 - .11 = .14

Where:

D_q = a decimal fraction representing the increase in the cost of high quality carbon black over conventional carbon black

D_d = a decimal fraction decrease in the cost of carbon black with higher quality, due to the need for smaller amounts

The additional materials which we would need to account for the wideness of the tire might be represented as a three inch (7.62 cm.) increase in width on a 75.15 tire, a thirty-five percent increase in the parts of the tire beneath the tread, and including the tread. This portion of the tire comprises about forty percent of the surface area of the tire, and includes carcass, belts, non-skid, and tread rubber. We multiplied the increase in width (.35) times the relevant proportion of the tire (.4) to determine an approximation to the increased materials needed due to width. We added .12 to this result to represent the factor of .35 increase in tread rubber depth needed on the widened section of tire. Twenty-six percent additional materials are needed for the ultra-wide tire.

$$\text{Materials Needed Due To Increased Width} = D_w (D_u) + D_w (D_h) = .35 (.4) + .35 (.35) = .26$$

Where:

D_h = the decimal fraction increase in tread rubber depth needed for 100,000 miles of tire service life as opposed to 40,000 miles

D_u = the proportion of a tires surface area which is covered by tread rubber

D_w = the decimal fraction representing the increased width needed for a TTW 100,000 mile tire

We summed the three effects discussed above to determine a surrogate measure of the increased materials needed for a TTW 100,000 mile tire.

H_m = the increase in rubber thickness plus
the increase in materials due to tread quality plus
the increase in materials due to the width of the TTW tire
= .05 + .14 + .26
= .45

100,000 MILE TIRES: INCREASED LABOR NEEDS (H_L)

A diagram of the tire manufacturing process is given in Kovacs (35).

Labor costs to produce a TTW tire could increase in direct proportion to the additional materials used; certainly TTW tires would require that a greater number of pounds of rubber and materials be processed: (1) through tire cord weaving dip and calendering units; and (2) through Banbury, milling, and extruding machines. The tire vulcanizing process will take longer due to the increased thickness of tread rubber used. We estimated that labor costs associated with these components of the tire manufacturing would increase forty-five percent, in accordance with H_m, for 100,000 mile tires.

The time requirements of cutting, bead coating-winding-and building, tire assembly, and final inspection (45% of the operations) would not increase significantly, however; a tire builder, for example, still has the same number of pieces to assemble with a TTW tire as he does for a conventional tire. Tire Builders are the most skilled of the tire labor force; they are on a relatively high wage scale. The labor costs, per tire, of the tire builder, cutting, bead, and inspection components would then, not increase for a 100,000 mile tire.

Based upon this analysis we used a figure of twenty-five percent as an estimate of increased labor costs for the TTW tire. $H_L = .25$

OVERHEAD COSTS: 100,000 MILE TIRES (H_o)

It would seem that overhead costs per tire, the "burden", would increase dramatically with the decreased production throughput volume implied by 100,000 mile tires; the fixed costs of production must be allocated for accounting purposes, over a smaller volume of tires. To determine the correctness of this idea we examine, "What is overhead?".

Overhead expenses include:

1. Repair labor and materials
2. Energy costs
3. Water and waste processing costs
4. Depreciation on equipment
5. Property taxes
6. Insurance
7. Salaries and wages of non direct production personnel
8. Research
9. Other.

There is no reason to assume that a tire manufacturer would maintain the system of overhead associated activities if he decreased his production volume. Most of the expenses would be decreased. Obviously, the energy requirements would be smaller with a smaller production volume; water and waste processing requirements would be similarly smaller. Some plant and equipment would undoubtedly be sold off and this would decrease depreciation, property taxes, repair labor and materials, and insurance costs. A smaller non direct work force would be needed to manage the production. Research might remain at the same level. It seems, then, that a smaller quantity of overhead costs remains to be allocated over the smaller quantity of 100,000 mile tires. It is not inconceivable that overhead costs increase, but by a small amount.

Further, the 100,000 mile tire alternative clearly recognizes that, eventually, a large percent of the replacement tire market will be eliminated or transformed to provide other goods and services. The firms that remain to produce the 100,000 mile tires will have the same overhead costs per tire as before provided that they operate at the same production volume. For these firms the overhead costs per tire will remain about the same as for conventional tires or, at most, will have an increase proportional to the increased material usage. Some of the overhead categories--depreciation, taxes, and insurance--would not increase if excess capacity already existed for the manufacturers. Excess capacity does exist for most tire manufacturing equipment--at least for the more expensive equipment such as the Calender and Banbury machines. Consequently a figure representing less than the forty-five percent increase in overhead would be justified.

We used a figure of $H_o = .40$ to represent this increase for those firms that would remain in the industry to produce the 100,000 mile tires.

PRODUCTION COSTS: 100,000 TTW TIRES

The TTW 100,000 mile tire is essentially a current steel belted radial tire with increased width and tread depth; in addition it uses top quality (truck) tread rubber. To calculate its cost we combined the cost components, studied above, as follows:

$$H = C_r + C_r S_m H_m + C_r S_L H_L + C_r S_o H_o$$

$$= C_r(1 + S_m H_m + S_L H_L + S_o H_o)$$

Where:

H = the production cost for a TTW 100,000 mile tire.

C_r = the cost of producing a current steel belted radial passenger car tire, excluding manufacturers profit.

S_m = the decimal fraction of a steel belted radial tire's production costs attributable to materials, only.

H_m = a number representing the additional amount of materials needed to obtain 100,000 miles.

S_L = the decimal fraction of a steel belted radial tire's production cost attributable to labor, only.

H_L = a number representing the additional labor needed to produce a 100,000 mile tire.

S_o = the decimal fraction of a steel belted radial tire's production costs attributable to "overhead".

H_o = a number representing the additional overhead which must be allocated to a 100,000 mile tire.

This Equation says:

H = Cost of a current steel belted radial tire plus
the additional materials costs plus
the additional labor costs plus
the additional allocation for overhead expenses.

The cost of a current single stage steel belted radial tire, with manufacturers' profits included, from Table E-5 is $22.12. C_r, excluding manufacturers' profits, is $21.68. The data for S_m, S_L, and S_o is given in Table E-7. The additional materials proportions ($H_m = .45$), Labor ($H_L = .25$), and overhead (H_O = .40) needed for TTW 100,000 mile tires, were developed in the previous sections. Our estimated cost for a 100,000 mile TTW tire is, accordingly:

$$H = 21.68\ (1 + (.475)(.45) + (.275)(.25) + (.250)(.40)$$

$$= 21.68\ (1.38) = \$29.92$$

A 100,000 mile TTW tire will cost about thirty dollars, excluding manufacturer's profits, to produce. An equally important question is, "At what price would these tires sell?"

SALES PRICES: 100,000 MILE TIRES

Tire sellers have the option of selling 40,000 mile steel belted radial tires that last four years (at 10,000 miles per year), or TTW 100,000 mile tires that last ten years. This situation may be formulated as a present value problem to determine a reasonable selling price for 100,000 mile tires.

TABLE E-8. GROSS PROFITS OF FIVE 40,000 MILE TIRES

Beginning of year	PV factors		Steel radial gross profits	Present value of gross profits	
	10%	20%		10%	20%
1.0	1.000	1.000	$42.59	$42.59	$42.59
5.0	.633	.482	$42.59	$29.09	$20.53
9.0	.467	.233	$42.59	$19.89	$ 9.92
13.0	.319	.112	$42.59	$13.59	$ 4.77
17.0	.218	.054	$42.59	$ 9.28	$ 2.30
		Totals	$212.95	$114.44	$80.11

The present values of the gross profits from five 40,000 mile tire sales are $114.44 discounted at ten percent and $80.11 discounted at twenty percent. These values may be used to determine a price for the 100,000 mile tire. Two 100,000 mile tires are equivalent to five current 40,000 mile steel belted radial tires. Based upon this we calculated the gross profits from two 100,000 mile tire sales for the ten and twenty percent discount rates:

G_h: 10% calculation

$G_h + .424G_h = 114.44$

$G_h = 114.44/1/424 = \$\ 80.36$

G_h: 20% calculation

$G_h + .162G_h = 80.11$

$G_h = 80.11/1.162 = \$\ 68.94$

$68.94 to $80.36 gross profits per 100,000 mile tire will be necessary, from the tire industry's viewpoint, if the 100,000 mile tire is to be profitable as compared to current steel belted radial tires.

If we add the $30 production cost to this gross profit value we obtain an estimate of a price for 100,000 mile tires which should be very reasonable from the tire industry's viewpoint. This price is $ 98.94 to $110.36. About $100 would be a reasonable price for a 100,000 mile tire.

In current dollar figures, if tire sellers were to sell 47.5 million 100,000 mile tires per year at a price of about $100 each, they would make more gross profit than if they were to sell 150 million 40,000 mile tires per year at a price of $65.50. In general, it is better to sell fewer high quality tires at higher prices than to sell larger quantities of lower quality tires at lower prices.

100,000 MILE TIRES AND THE CONSUMER

Consumers may also be the beneficiaries of a 100,000 mile tire. At current steel belted radial tire prices consumers may be expected to pay $65.50 per tire every four years. In twenty years this totals $327.50 per axle on a car; the present value of this amount at a discount rate of ten percent is $190.27. Tire sellers can sell 100,000 mile tires at $100 each, one now and one at the beginning of year eleven, to the consumer. The present value of these two sales is $142.40. The consumer can save $47.87 per axle each twenty years. Obviously, both the consumer and the tire seller can get more for less with 100,000 mile tires.

FUEL CONSUMPTION: 100,000 MILE TIRES

TTW 100,000 mile tires use about forty percent more materials than do current steel belted radial tires; a TTW tire, then, may be represented as being forty percent heavier than a current 40,000 mile tire. If a current tire weighs 30 pounds (13.6 Kg.) when new, then TTW tires would weigh 42 pounds (19.1 Kg.) each. This represents an increase in weight of twelve pounds (5.4 Kg.) per tire. This increased wieght has an effect on the gasoline mileage obtained from an automobile and this effect might be represented as a cost of 100,000 mile tires in our analyses. We examine the cost of increased fuel consumption below.

We estimated the change in fuel consumption which would be associated with a twelve pound (5.4 Kg.) increase in the weight of a TTW tire. a 5000 pound (2268 Kg.) automobile consumes about 100 percent more fuel than does a 2500 (1134 Kg.) automobile. Over the ten year life of his vehicle the owner usually spends nearly sixty percent of the price of the car on gasoline. For a $5000 automobile, $3000 would be spent on gasoline in ten years and this represents $1200 during the four year life of a current tire. An increase in weight of twelve pounds (5.4 Kg.) on a 3750 pound (1701 Kg.) car represents a .3 percent increase in weight. If the relationship between fuel consumption and vehicle weight is direct such that a .002 percent increase in weight results in a .3 percent increase in fuel consumption, then an additional cost of $3.84 per 100,000 mile tire per four years would be incurred. Four 100,000 mile tires would add $15.36 to consumer fuel costs each four years. This cost is significant, yet it is significantly less than the $22.70 consumer savings (Table 3) obtainable in the cost of tire services. And there is substantial possibility that 100,000 mile tires could be sold at even less than the $107 price used to represent 100,000 mile tires in the Tires II analysis. For example, if a tire manufacturer were satisfied with a $90 price per tire representing a markup, from the $30 production cost, of 200 percent, consumers could obtain tire cost benefits much greater than the $22.70 found in this research.

The LHP 100,000 mile tire need not have any increased fuel consumption as compared to current tires; the effect of higher operating pressures is to increase gas mileage. The operating pressure of TTW tires could be slightly increased to offset any increase in gasoline consumption which would occur because of increased weight. DTR 100,000 mile tires, when developed, will have no increase in weight. The efficiency of fuel use for 100,000 mile tires, then, can be the same as for current tires.

SUMMARY

100,000 mile tires are technically feasible to produce and are marketable. They can offer increased profits for tire sellers and decreased costs for tire services to consumers. 100,000 mile tires will provide additional benefits in the areas of safety, conservation, and solid waste management.

GLOSSARY OF SYMBOLS AND DEFINITIONS

A = the proportion of a 40,000 mile tire's manufactured value (manufacturer's selling price) that a solid waste tire retains

A_b = the area, in square yards, of a Phoenix, Arixona, city block 560 feet by 60 feet

C_a = the costs of grading a worn tire for possible reuse

C_b = the batch collection costs per worn tire

C_c = the haul costs per solid waste tire

C_d = the costs of grinding a solid waste tire

C_e = the costs of chopping up (shredding) a solid waste tire

C_f = the average cost of a ½ inch asphalt concrete finishing coat (ACFC) in conventional road repairs

C_g = the cost of processing a solid waste tire by Cryogenics

C_h = handling costs per solid waste or worn tire

C_i = a cost index which indicates the decimal fraction increased cost that radial tires incur as compared to belted bias tires

C_L = landfill costs per solid waste tire

C_p = the production cost for a belted bias tire, including manufacturer's profit; the average price to wholesalers

C_r = the average store rental cost for a tire dealer

C_s = the average cost of one inch of asphalt concrete in road repairs

C_{sp} = the present value of road repairs avoided each ten years with the tire asphalt rubber repair process

C_{tra} = tire asphalt rubber costs for repairs to a 560' X 60' city block

C_t = the cost of retreading a tire; production processing cost

C_u = the haul cost per solid waste tire

D_c = the pounds of carbon obtainable from one solid waste tire using the TOSCO, pyrolysis/destructive distillation, process

D_d = a decimal fraction decrease in the cost of carbon black with higher quality, due to smaller amounts needed

D_h = the decimal fraction increase in tread rubber depth needed for 100,000 miles of tire service life as opposed to 40,000 miles

D_i = the decimal fraction solid waste decrease per tire for the service life design which is used with alternative "i"

D_o = the barrels of recovered oil obtainable from one solid waste tire using the Tosco destructive distillation process

D_q = a decimal fraction representing the increase in the cost of high quality carbon black over conventional carbon black

D_s = the tons of scrap steel obtainable from one solid waste tire using the Tosco destructive distillation process

D_t = a decimal fraction that indicates the part, by volume, that tread rubber constitutes of a tire's materials

D_u = the proportion of a tire's surface area which is covered by tread rubber

D_w = a decimal fraction representing the increased width needed for a TTW 100,000 mile tire

E = the costs of maintaining environmental quality; landfill costs are used as a surrogate in this work

EXAV= the average selling expenses for a 40,000 mile steel belted radial tire

EXL = a low estimate of selling expenses for a 40,000 mile steel belted radial tire

F_* = a tire dealer's gross profit rate on selling price for 40,000 mile steel belted radial tires

F_5 = a tire dealer's gross profit rate on the selling price of a 40,000 mile retreaded tire

F_6 = a tire dealers gross profit rate on the selling price of a 100,000 mile tire

G = the application rate for tire asphalt rubber, in gallons per square yard of road repaired

G_h = the gross profits obtained on the sale of a 100,000 mile tire

H = the average production cost for a 100,000 mile TTW tire

H_L = a decimal fraction representing the increased labor needed to produce a 100,000 mile tire

H_m = a decimal fraction representing the increased materials needed in producing a 100,000 mile tire

I_d = an interest/discounting rate decimal fraction for business investments

I_g = an interst/discounting rate decimal fraction for governmental funds

K_d = a decimal fraction representing high administrative and marketing costs as compared to production costs

K_h = a decimal fraction of sales price factor representing administrative and marketing costs for 100,000 mile tires
K_L = a decimal fraction of production costs factor used to represent low administrative and marketing costs
K_r = a decimal fraction of production costs factor used to represent administrative and marketing costs of retreading
M_* = average mileage service life of a steel belted radial tire in the United States in 1975: 40,000 miles
M_5 = average total mileage service life for belted (steel) radial tires with one retreading; including both original and retreaded life
M_6 = average mileage service life for tires designed to last, the average life of an automobile: 100,000 miles
N = the proportion of a solid waste tire that it takes to obtain one pound of tire asphalt rubber additive
N_a = the number of tires in a landfill six feet deep measured at one cubic foot per tire
N_b = the number of whole tires used in one city block of tire asphalt rubber road repairs
N_s = the number of whole tires used in one square yard of tire asphalt rubber road repairs
O = the opportunity cost, to tire manufacturers, of increasing retreading by one tire
O_L = the decimal fraction of resource recovery products value attributable to labor
P = the weight, in pounds per gallon, of tire asphalt rubber
P_a = the price per acre of land reclaimed by fill with shredded tires
P_b = the average retail price of a belted bias tire
P_c = the selling price per pound for recovered carbon
P_g = the selling price for a bag of crumb rubber reprocessed by Cryogenics
P_h = the average retail selling price for a 100,000 mile tire
P_* = the average retail selling price of a 40,000 mile tire
P_i = the corporate profits for alternative "i"
P_o = the selling price for a barrel of recovered oil from solid waste tires
P_r = the retail selling price of a retreaded 40,000 mile radial tire
P_s = the selling price, per ton, for scrap steel
P_t = the price per ton of coal
R = the average production cost for a 40,000 mile steel belted radial tire

R_c = the cost of conventional repairs to a city block which is 560' by 60'

R_L = the mileage of cracked roads repaired temporarily each year in the United States (as opposed to rebuilt, permanently repaired, roads)

R_p = the proportion of a worn tire that is rubber

R_r = the cost, per square yard, for materials and application of tire asphalt rubber

R_w = the average width of a U.S. road

S_{ip} = the present value of the interest earnable on the road repair costs avoided by the asphalt rubber process, measured over a ten year period

S_L = the proportion fo a tire manufacturer's average selling price, per tire, allocable to labor costs

S_m = the decimal fraction proportion that materials comprise of a manufacturer's selling price per tire

S_o = the decimal fraction proportion of a tire manufacturer's average selling price allocable to overhead costs

S_p = the average proportion of a tire dealer's physical space used for storage of worn tire casings

S_r = the decimal fraction of a retreaded tires price attributable to labor

T = the corporate profits tax rate

T_w = the number of solid waste tires which may, potentially, be used in tire asphalt rubber road repairs each year in the United States

U = the average number of miles driven per car per year

U_c = the heat value in British Thermal Units (BTU) obtainable from a pound of coal

U_r = the heat value in British Thermal Units (BTU) obtainable from one pound of worn tire rubber

V = the average inventory of worn tire casings held by a tire dealer

W_{di} = the waste decrease per tire per year as compared to 40,000 mile tires

W_p = the proportion, by weight, of tire asphalt rubber, which is worn tire rubber

W_t = the average weight, in pounds, of a solid waste tire

W_{wi} = the decimal fraction of solid waste tires per unit time that remain with any of the solid waste decreasing alternatives

Y_* = the years of service life of a 40,000 mile steel belted radial tire, the reference tire system

Y_i = the number of years of service life obtainable from the tire design associated with alternative "i"

Y_5 = the total service life of a retreaded steel belted radial tire including original life plus retreaded life

Y_6 = the service life of a 100,000 mile tire